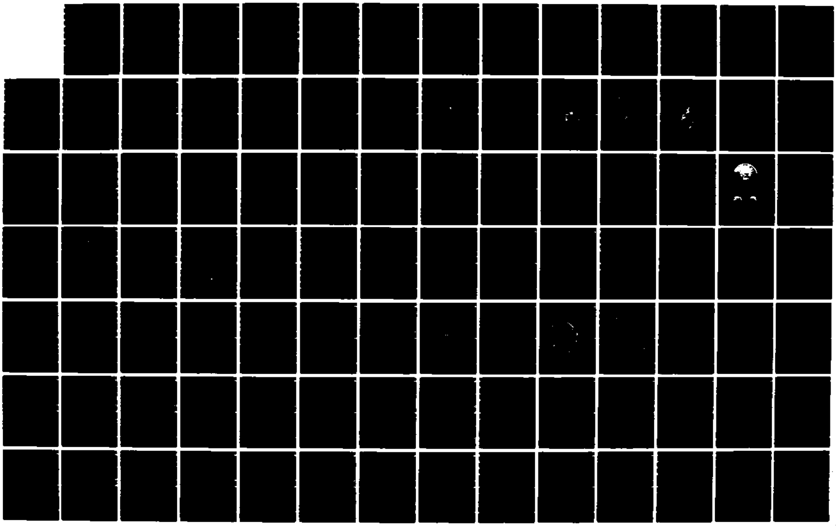
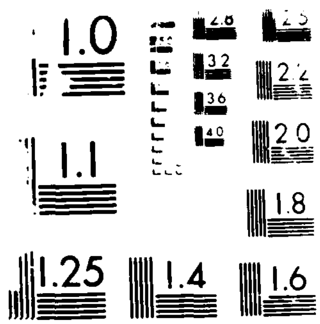
AD-A179 233 A SYSTEMS ANALYSIS OF EMERGENCY ESCAPE AND RECOVERY 1/2
SYSTEMS FOR THE US SP.. (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. B K KELLY

UNCLASSIFIED DEC 86 AFIT/GSO/AA/86D-5 F/G 6/7 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
3.2
3.6

A SYSTEMS ANALYSIS OF

EMERGENCY ESCAPE AND RECOVERY SYSTEMS

FOR THE U.S. SPACE STATION

THESIS

Brian Kelly
Captain, USAF
AFIT/GSO/AA/86D-5

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSO/AA/86D-5

A SYSTEMS ANALYSIS OF

EMERGENCY ESCAPE AND RECOVERY SYSTEMS

FOR THE U.S. SPACE STATION

THESIS

Brian Kelly
Captain, USAF
AFIT/GSO/AA/86D-5

AFIT/GSO/AA/86D-5

A SYSTEMS ANALYSIS OF EMERGENCY ESCAPE AND RECOVERY SYSTEMS FOR THE U.S. SPACE STATION

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fullfillment of the

Requirements for the Degree of

Master of Science in Space Operations

Brian Kelly, B.S.

Captain, USAF

December 1986

Acknowledgments

In preparing this thesis I had a great deal of help from some wonderful people. Special thanks go to my faculty advisor, Capt Stu Kramer, for his diligent efforts and understanding patience in guiding me through this effort. I also wish to thank Col Mike O'Connell for his excellent leadership and friendship throughout the trauma of AFIT. I am deeply indebted to Mr. Lanny Jines for his endless hours of help and support. Finally, I wish to thank my wife Cheryl and kids, Dalena and BJ, for their understanding, patience, and love throughout my tour at AFIT.

Brian Kelly

Table of Contents

List of Figures

List of Figures (Cont)

List of Tables

Abstract

Recent designs for the U.S. manned space station have crews on board the space station without any means of emergency escape for periods of up to 90 days. This investigation analyzes emergency escape and recovery systems for use on the space station in an effort to find the "best" escape device.

Initially, the objectives to be met by an effective escape device were identified along with ~~with~~ the corresponding measures of effectiveness (MOE) for each objective. Fifteen alternative escape systems were found that could be used on the manned core portion of the space station complex. A preliminary analysis reduced the number of alternatives considered for more detailed analysis to six. These final six, The Maneuverable Entry Research Vehicle (MERV), Emergency Astronaut Re-entry Parachute System, Manned Orbital Escape System (MOSES), MOOSE (Man out of Space Easiest), and Apollo Command Module, were compared on the basis of their calculated MOEs using multi-attribute utility theory.

The overall utilities for each of the final six alternatives were calculated for two crew sizes, 3-man and 8-man. MOSES was found to consistently rate the highest overall utility for both manning scenarios. The next best alternative was the Apollo Command Module.

Recommendations include examining the potential of using an escape device as an orbital transfer vehicle, and to conduct a future detailed comparison of MOSES and the Apollo Command Module for use on the space station as an emergency escape system.

A SYSTEMS ANALYSIS OF EMERGENCY ESCAPE AND RECOVERY SYSTEMS FOR THE U.S. SPACE STATION

I. Introduction

Background

On January 25, 1984, during his state of the union address, President Reagan directed NASA to develop a permanently manned space station within ten years (38). Following the President's directive NASA established a goal to have an operational space station by 1994 (35:12). The aim of NASA's goal is a space station complex composed of a manned station in a circular orbit inclined 28.5° at an altitude of 450 kilometers, an unmanned platform in the same orbit with varying altitude, and another unmanned platform in a 500 to 1000 kilometer polar orbit (35:42). What is envisioned is a multi-purpose complex that will serve many technological and international endeavors including materials experimentation, earth observation, satellite repair, and medicine (35:5).

This investigation focuses on the manned core space station, often simply referred to as the space station. It is this space station that will fulfill the President's directive of having a permanent and continual manned presense in space.

The space station will be different form the United States' Skylab program and the Soviet Unions' Salyut 7 space station in many ways. One critical difference is in emergency escape capability. The future space station is currently designed to have no earth return system unlike Skylab

which used an Apollo Command Module and Salyut 7 which is serviced by expendable Soyuz transportation capsules (35:4). The space station will not have a continuous stand by space shuttle (36:1). During full operation the space station is to be serviced by shuttle resupply missions with 90 day intervals. Optimistic projections, prior to the Challenger accident, were that the shuttle was capable to be launched for emergency rescue within 28 days (46).

Continual operation in the hazardous environment of space will add unique elements of danger to the astronauts on the space station. Some of these potential hazards include the danger of life support system failure, on-board fire or contamination, meteorite collision, and man-made debris impact. These hazards, combined with the shuttle's inability for quick response, necessitate an examination of emergency escape and recovery systems for the space station.

Problem Statement

A need exists to identify different space station escape systems and compare those systems in terms of cost and effectiveness. What is a low cost and yet effective method of emergency escape and recovery? Given two different manning scenarios which escape and recovery system is best? How many escape systems and of what type are needed to support all astronauts on the space station? This Thesis represents the culmination of an effort to determine an effective and low cost method of crew escape and recovery for the space station for a three man and an eight man crew.

Study Objectives

The main objective of this research is finding a low cost and highly effective space station escape system, specific subobjectives are:

1. Identification of pertinent background information on the space station such as it's size, configuration, design, use, and potential docking locations for escape modules.
2. Identification of hazards that could lead to emergency escape from the station.
3. Defining objectives to be met by an effective emergency escape device.
4. Identification of alternative designs for space stations escape systems.
5. Evaluation and ranking of alternatives with respect to objectives.

Scope

This Thesis deals with escape devices suitable for use on the manned space station. The analysis does not include mechanisms not attached to or inside of the space station. External rescue vehicles or similar operations were not considered on this analysis. The hazards that may lead to emergency escape are identified in general form. Their relative probabilities of occurance are not included in this analysis. This limits the focus of the research to escape systems and not the hazards associated with manned space operations, an area of research on it's own.

The design of the space station is a continuing process that is just beginning. This analysis focusses on the dual keel design of the space station as of March 1986 (35). The general findings, however, can be used for any variations that use module components.

Methodology

The general approach to this problem is that of a systems analysis. Systems analysis is a problem solving technique using some type of step by step methodology (40:3). Several types of systems analysis outlines exist. The following steps are generally included in this methodology (12:5):

1. defining the problem
2. identification of objectives to be achieved
3. determining measures of effectiveness used in deciding among alternatives which achieve the objectives
4. identifying alternatives
5. determining the cost and effectiveness of each alternative
6. comparing alternatives and making recommendations in terms of cost and effectiveness

Since the problem has been defined, the first step in this investigation is determining the objectives to be achieved by a potential emergency escape system. Chapter II begins with a general discussion on the space station and includes detailed drawings covering the dual keel design. Information on manning requirements, space station design, and potential hazards are combined to determine objectives. Following that, the measures of effectiveness used later in the analysis are developed.

Chapter III begins by introducing escape devices that could be used on the space station. This serves as the identification of alternatives, a critical step in systems analysis. Included is information on how the various systems could be used and their limitations on crew size and capability. The chapter concludes with an analysis of the alternatives in

terms of the objectives determined in Chapter II. This is accomplished for a 3-man scenario and an 8-man scenario for crew size on the space station.

The final step is comparing the alternatives. In Chapter IV Multi-Attribute Utility Theory is used to compare the overall utility of the various alternatives. Recommendations are finally made on the "best" escape system according to the objectives and criteria outlined in the thesis. Areas requiring further evaluation are then discussed in the conclusion.

II. Measures of Effectiveness

Introduction

The first section of this chapter is a general discussion of the space station and its operation. The next section evaluates potential hazards and accidents that could lead to emergency escape from the station. In the third section the objectives that need to be achieved by an effective emergency escape system are discussed. In the final section, the measures of effectiveness used in comparing alternative systems are described.

Space Station

When designing an ejection seat for a fighter aircraft an escape systems engineer must know about the aircraft and it's operations. Similarly, an examination of emergency escape systems for the space station begins with a review of the space station itself. In chapter one, preliminary facts were mentioned about the three parts to the over-all space station complex. Additional facts on the space station enhance an understanding of this unique space system. The $10 to $13 billion projected cost for this space facility certainly underscores the interest that NASA has put into the program (11:53). The operational mission of the space station is what drives NASA to develop this technological marvel. The space station is a multi-purpose facility that will be utilized as a space laboratory, permanent observatory, servicing facility, transportation node, assembly facility, manufacturing facility, storage depot, and as a staging base for future deep space exploration (35). It will be permanently manned for up to thirty years (18:1). The international

involvement is demonstrated by the fact that Canada, Japan, and the European Space Agency have signed a memorandum of understanding with NASA that deals with their involvement in the technological endeavors and research efforts on the space station (35, 25). The international concerns do not stop at the research and development level. The routine operations on the space station may be accomplished by as many as 8 to 10 astronauts from various international backgrounds (19:2).

The proposed U.S. manned space station design consists of four 13.3 meter long living and working modules arranged in figure-8 pattern (41) (see Fig 2.1, 2.2, 2.3, 2.4). These modules are connected to a 145 by 110 meter truss work support structure. The modules are positioned in a geometric plane perpendicular to the plane containing the large support structure. Of these four pressurized modules, two will be constructed in the United States. One U.S. module will contain a laboratory (see fig. 2.8), the other will be the living quarters and space station operations module (see fig. 2.7). The remaining two will be a European Space Agency general purpose laboratory module and a Japanese experiment module. The four modules are interconnected by four connective nodes and two tunnels (see fig. 2.5, 2.6). Attached to the two nodes in the center of the figure-8 pattern are two airlocks to support EVA (Extra-Vehicular Activity) work. One of these connection nodes also supports a smaller logistics module. The outermost connecting nodes are used as docking ports for the space shuttle. These six point connecting nodes and the two airlocks may serve also as connecting points for escape modules. This is discussed later in this study.

The large truss-work structure supports a variety of other space station equipment. The 145 meter horizontal portion of the truss supports four 10.8 by 25.8 meter photo-voltaic arrays and two large solar dynamic collectors to provide the space station with 75 kilowatts of power (41:13). Also attached to it are eight thermal radiators. The vertical portion of this truss work is two 110 meter sections connected at the top, middle, and bottom by 45 meters of additional truss to form a huge rectangular structure. At the top and bottom of this rectangle is located a variety of antennae and test equipment. Along the vertical portion of this dual keel configuration is a mobile servicing center (41:16). This center houses two manipulator arms used for assembly of the space station and for moving large objects. The device will be attached to a trolley capable of moving along the vertical truss. The dual keel design allows for future expansion of the space station by providing more area to locate additional test instruments and other equipment (see fig. 2.4).

The interior living conditions and support requirements for the space station crew will focus on a closed loop water and oxygen recycling system. Wash water and cabin humidity will be totally recycled. Complete water recovery is expected for everything except feces with the only required resupply being nitrogen. Interior cabin pressure will be maintained at 14.7 psi because current data used for various experiments is at earth sea level pressure (41:14).

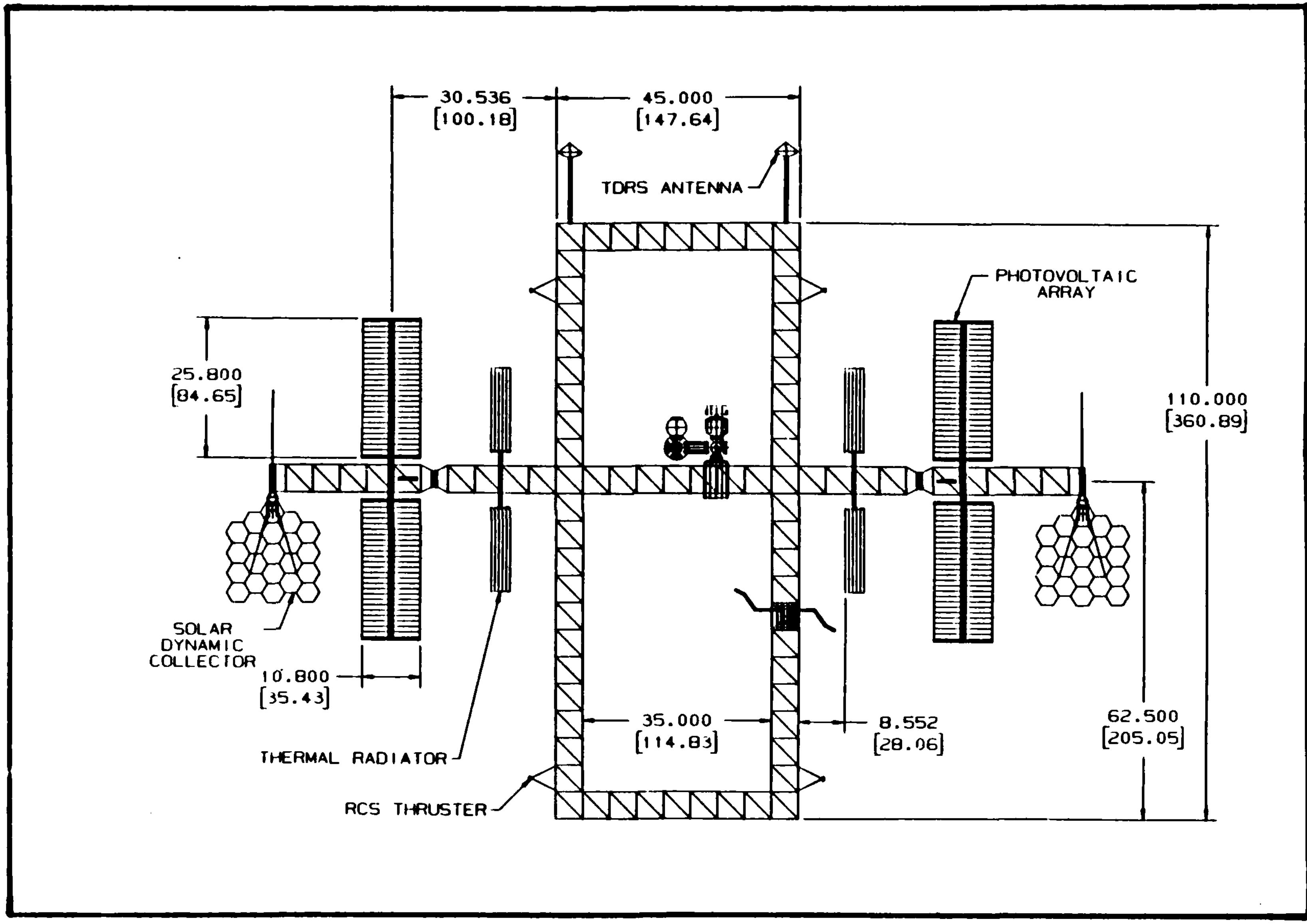


Fig 2.1 U.S. Space Station Front View (9)

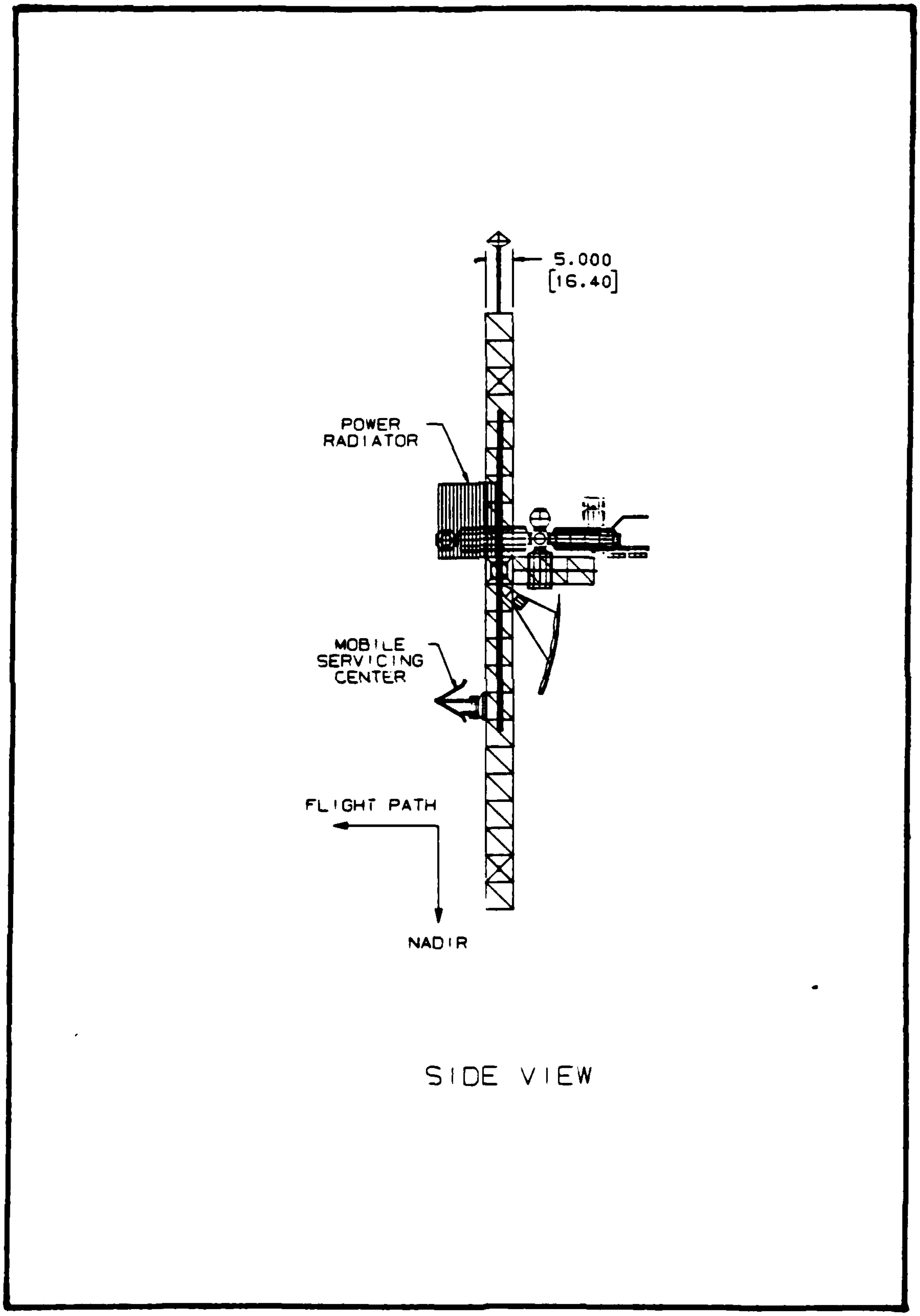


Fig 2.2 U.S. Space Station Side View (9)

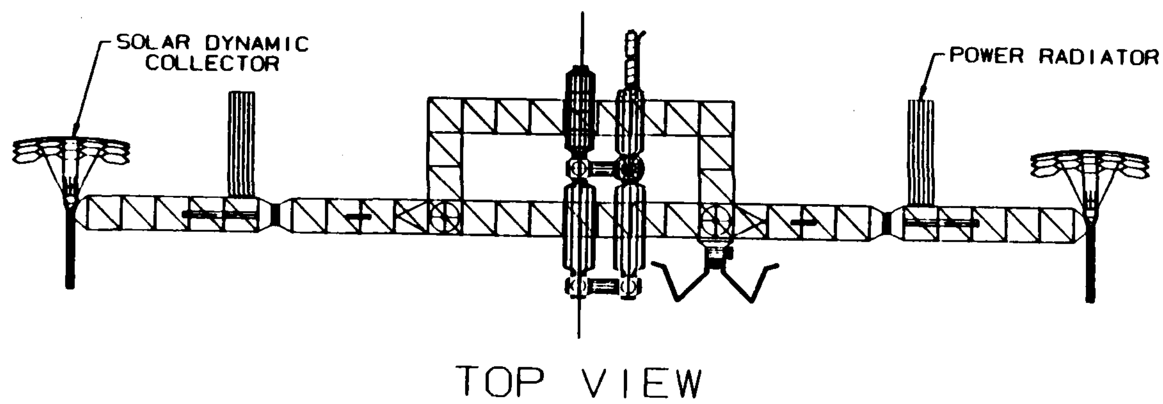


Fig 2.3 U.S. Space Station Top View (9)

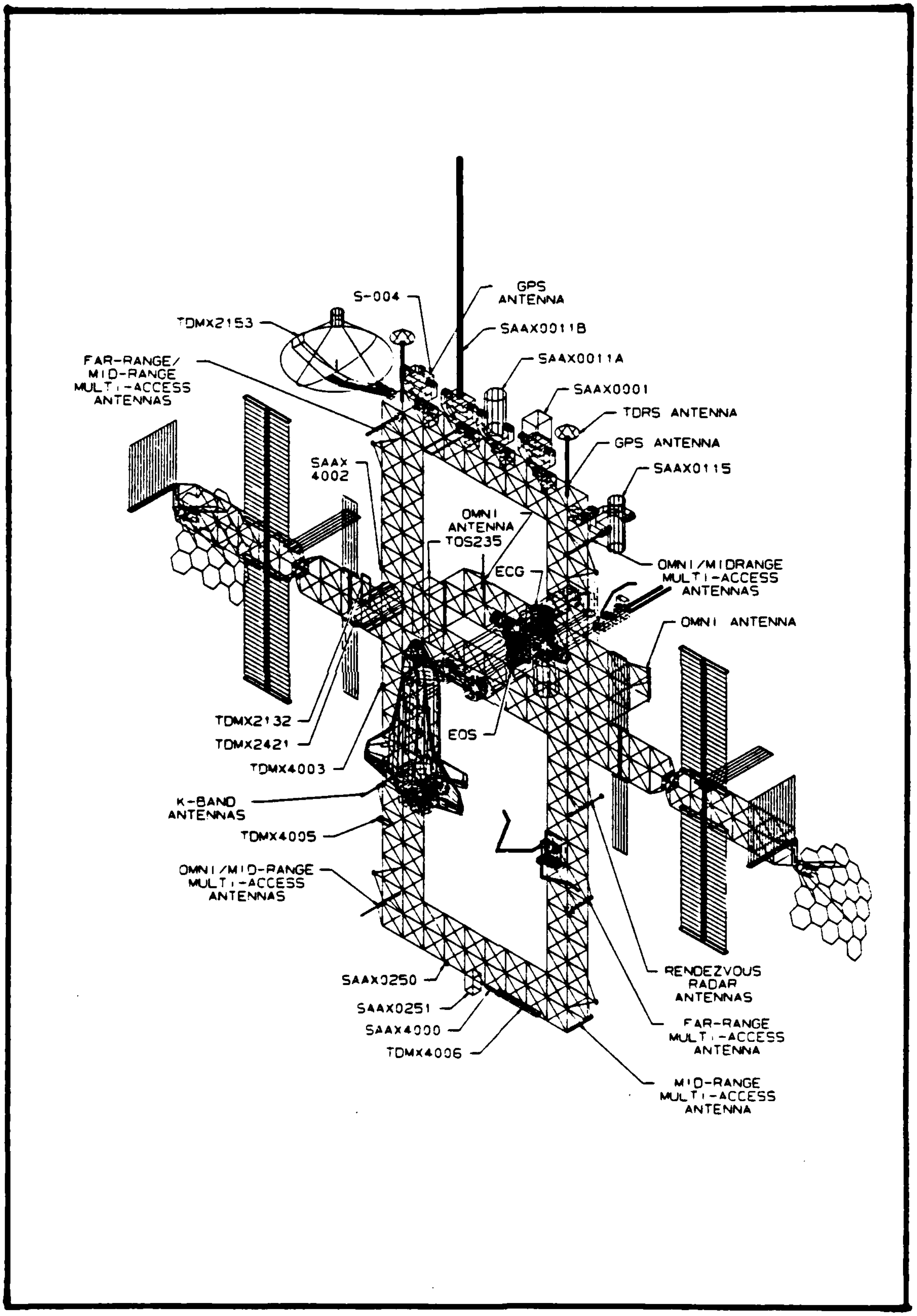


Fig 2.4 U.S. Space Station Isometric View with Docked Shuttle and Added Test Equipment (9)

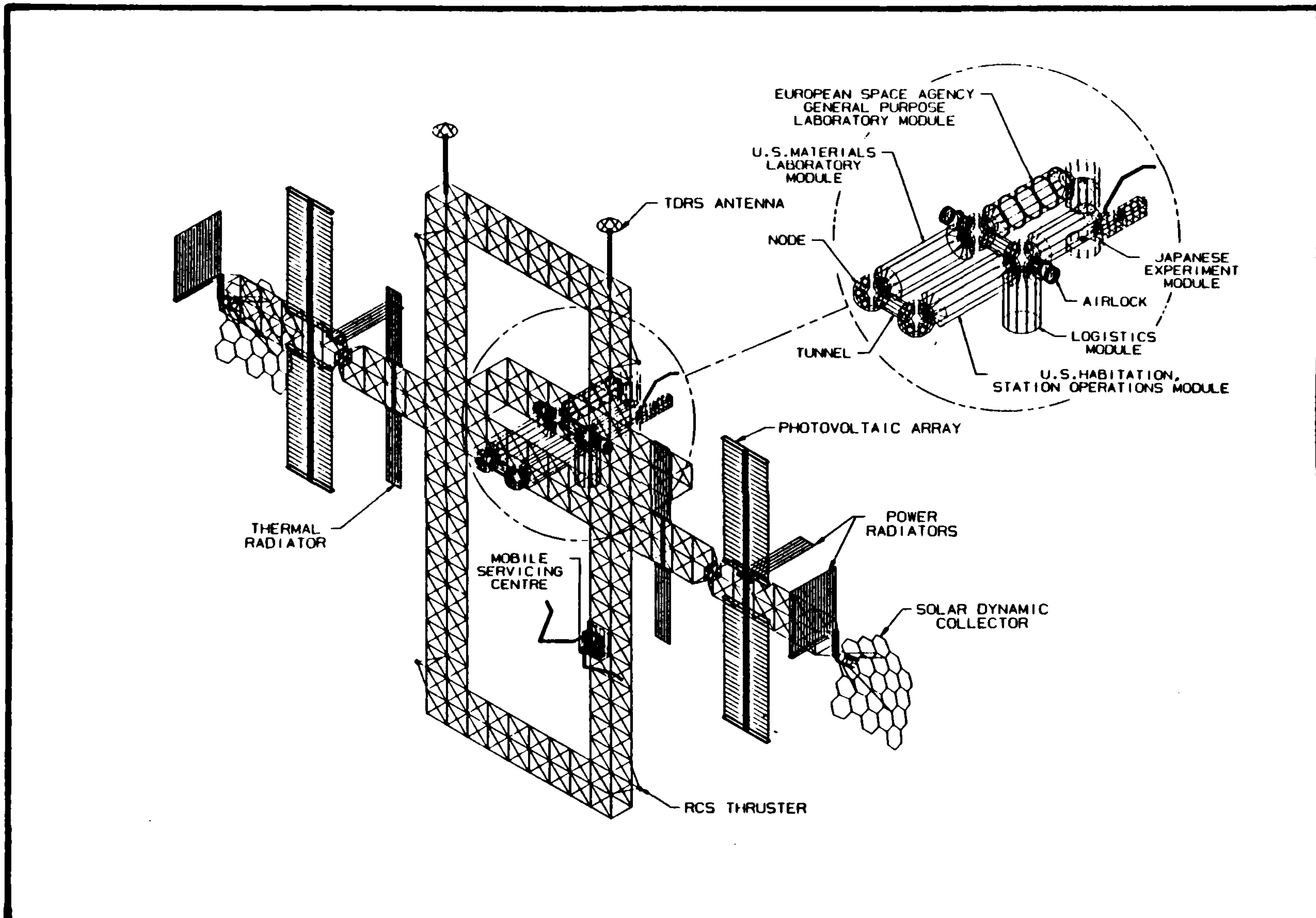


Fig 2.5 U.S. Space Station Isometric View with Module Arrangements (9)

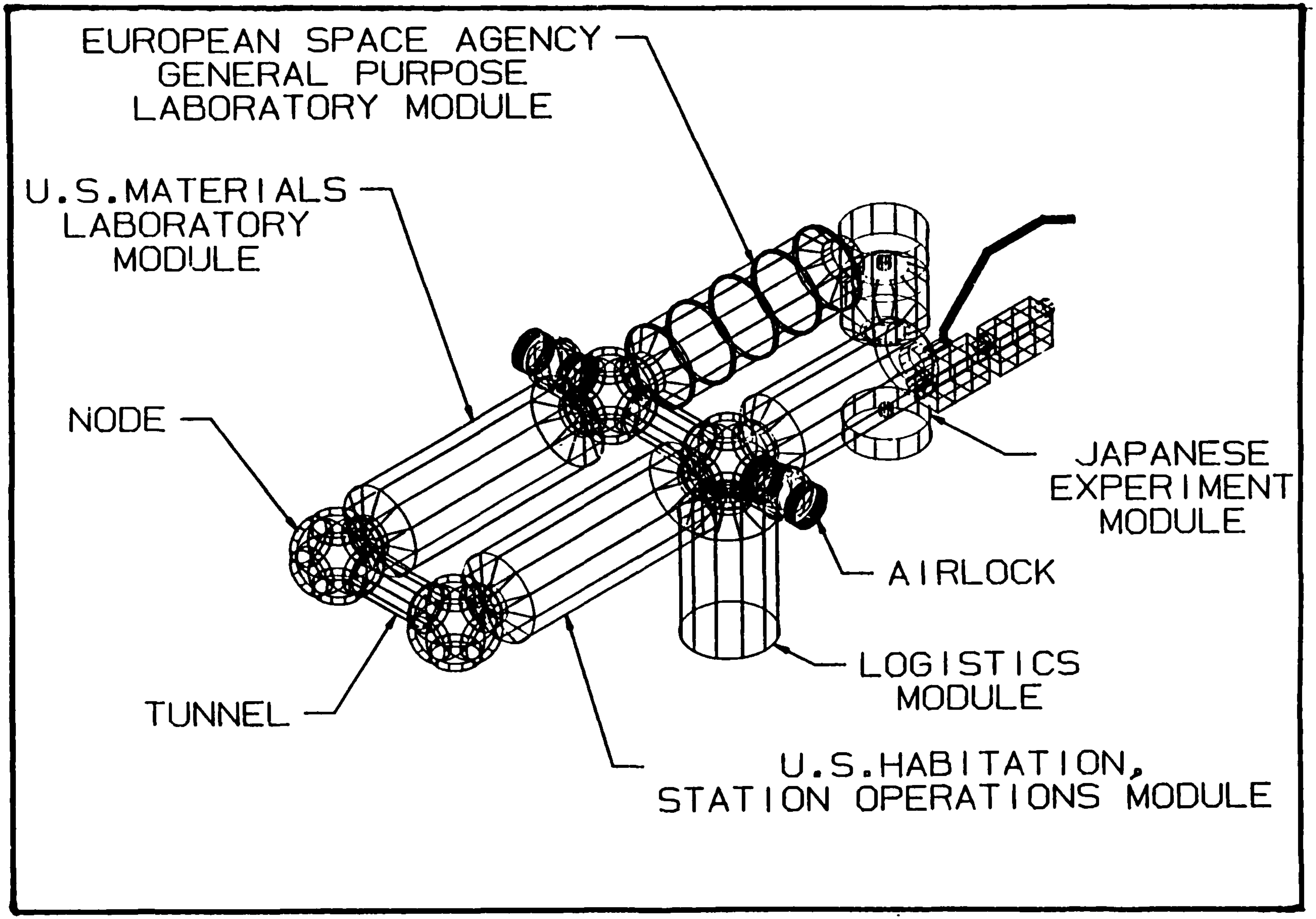


Fig 2.6 U.S. Space Station Module Blow-up (9)

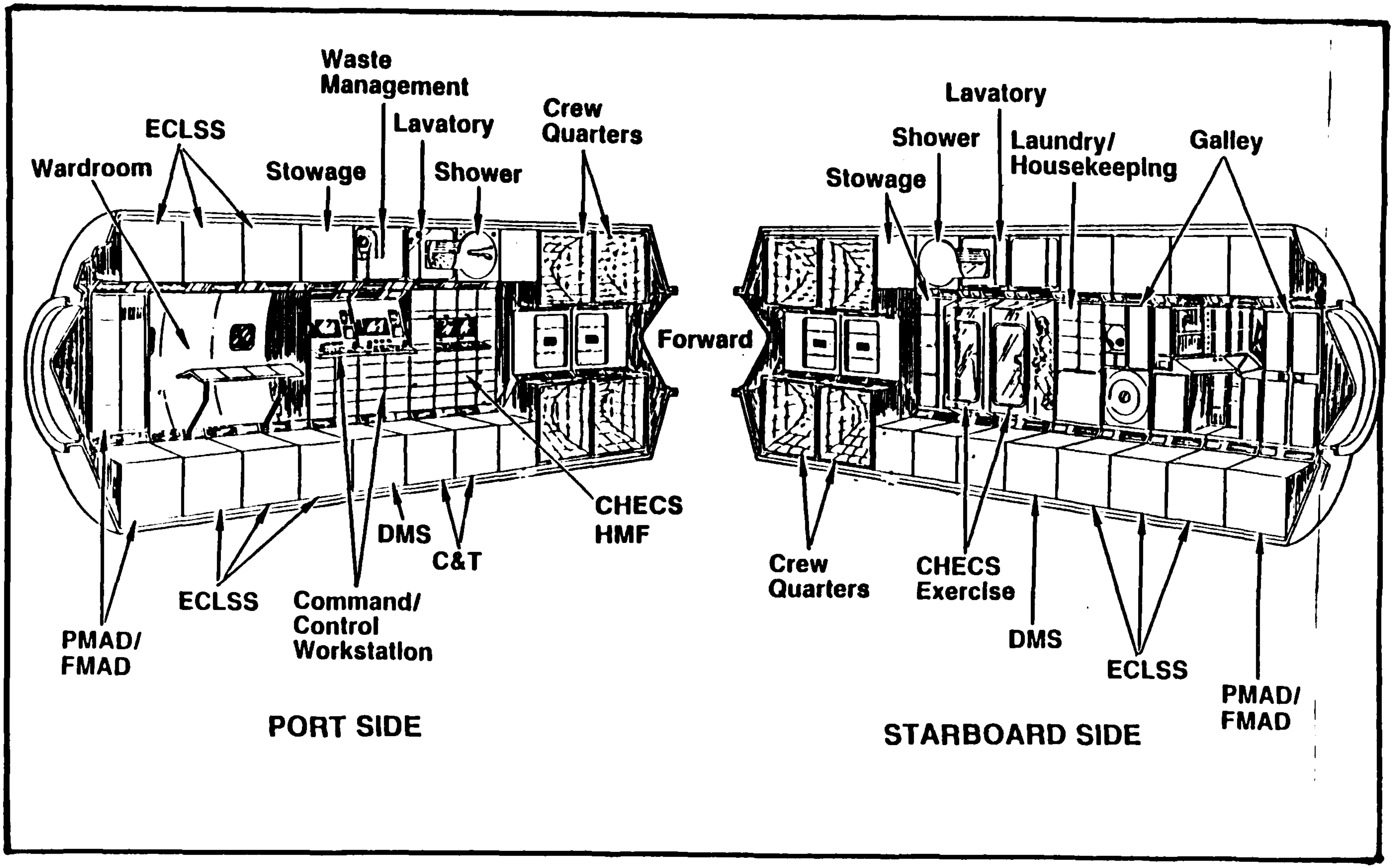


Fig 2.7 U.S. Living Module (22)

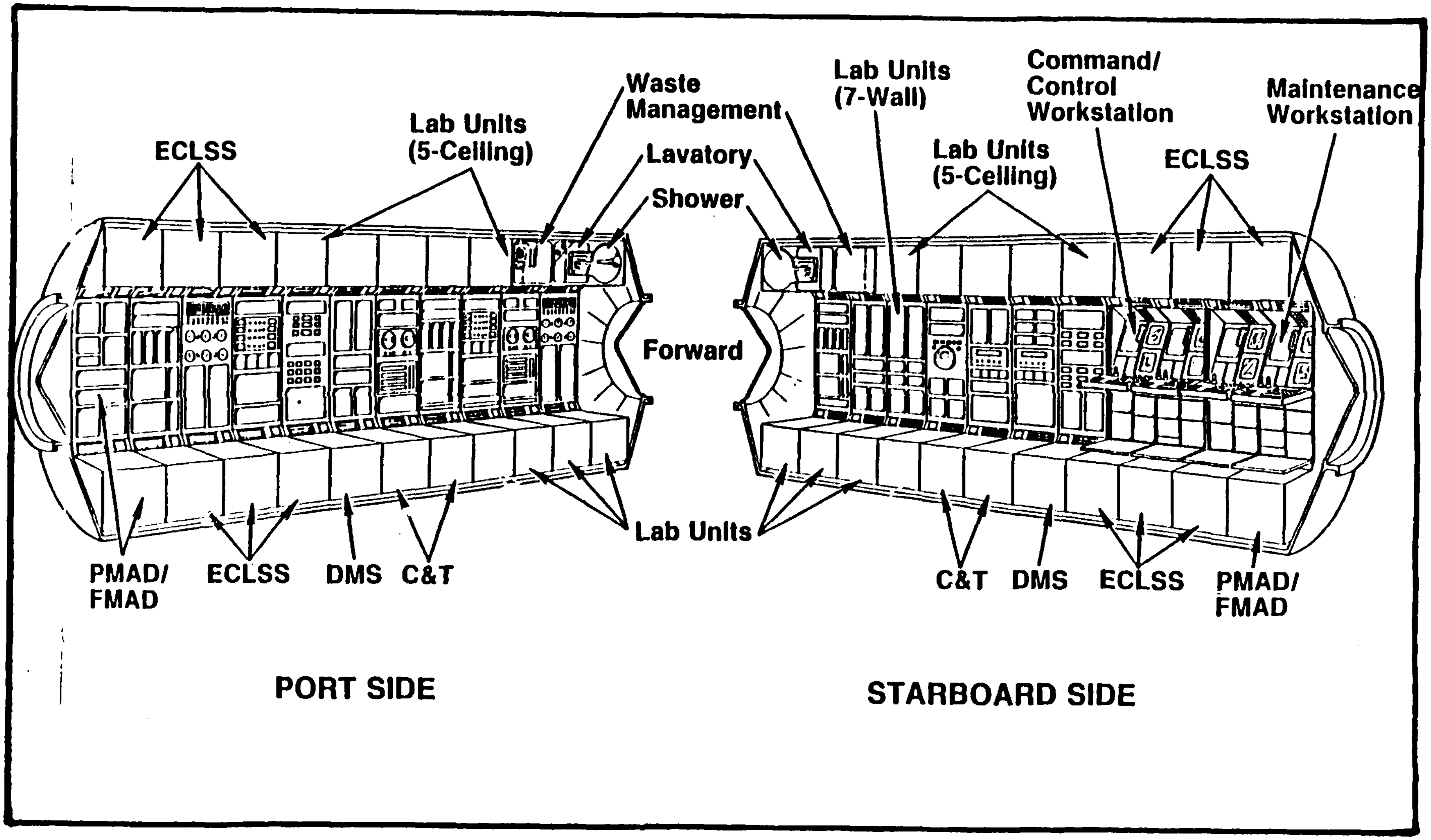


Fig 2.8 U.S. Laboratory Module (22)

Hazards

On April 13, 1970, the Apollo 13 lunar mission encountered serious difficulties when one oxygen tank exploded 56 hours into the flight with the crew and space craft over 130,000 miles from earth (14:1123). Fortunately, disaster was averted and the crew was safely returned to earth. This brings to light the question of what hazards await space station crew members that would require emergency escape in a timely manner.

Several researchers (50; 51; 24; 43) agree that the potential for man-made debris impacting the space station poses a real threat. Dramatic decompression and potential tumbling could result. The large size of the space station increases the probability of debris impact. Smith noted in his study (43:5) on the implications of an increasing space-debris population that the probability of the space station being struck by a four centimeter or larger piece of debris is .05 over a 10 year period. Wolfe, et. al, notes that the over 5,000 objects tracked by NORAD are steadily increasing over time and will continue to pose a threat to future space systems such as the space station (51:46). The speeds at which space debris would impact the space station makes the smallest particles deadly. A recent space station safety report noted that according to NASA astro physicist Donald Kessler, at Houston's Johnson Space Center, the impact velocity between two orbiting objects in the vicinity of earth would average 22,000 miles per hour (36:141). The same report said that at such speed, the collision force between two objects that each weighed one pound could release the same energy as the detonation of 20 pounds of TNT. An incident that attributes space debris as causing the destruction of a space

craft has been reported (36). What was suspected to be a piece of metal space debris reportedly hit and destroyed COSMOS 1275, a soviet navigation satellite, on July 24, 1981.

Other concerns for safety focus on the equipment inside the space stations living and working modules. To conduct various research experiments the space station will be equipped with 2,000 - 3,000 degree furnaces (19). This type of equipment and possible electrical short circuiting makes fire a potential hazard. Peercy, et. al, in their study (36:33) generated a space station crew safety check list. In addition to the hazard of man-made debris and fire, the list also includes such threats to the astronauts safety as tumbling/loss of control, biological or toxic contamination, injury/illness, grazing/collision, corrosion, mechanical damage, explosion, loss of pressurization, radiation, electrical shock, meteoroid penetration, stores/consumables depletion, intrusion/attack, structural erosion, orbit decay, and temperature extremes.

These potential hazards combined with the fact that current designs have the space station crew on-board the space station without any escape system or attached shuttle for periods of up to 90 days is a basic safety concern that generates studies such as this (49:1). The Soviet Union's Salyut 7 space station maintains an attached escape craft for a crew of three (35:3). Soviet scientist have reported using a training exercise for the Salyut cosmonauts called "urgent escape from the station" (36:125). The potential for disaster not only led the Salyut designers to include an escape craft but also encouraged the Soviets to actively train their cosmonauts in emergency escape procedures.

Objectives

In a systems analysis, one of the primary concerns is the development of the objectives that are to be met by the alternative systems. In this case the primary focus is the safety of the space station crew in the harsh environment of space. Therefore, an emergency escape device must be highly reliable and capable of handling a variety of catastrophes such as those discussed in the section above. An escape system must also be simple to use. The day of the test-pilot Astronaut Corps is increasingly giving way to scientists and engineers not trained in high velocity pilot techniques. These mission specialist astronauts may be incapable of performing complex re-entry maneuvering in a manual escape system. The possibility of injured or disabled astronauts leads to a requirement for an autonomous escape system which incapacitated personnel and non-pilot rated crew members could use.

A potential escape mechanism, if located on or attached to the space station should be light weight. The weight factor, as in all space systems converts to cost. In a safety related analysis it is often difficult to concern oneself with the element of expense. In this analysis, cost is a real concern and a factor that is not overlooked. A space escape system should be simple, inexpensive and should minimize technological breakthrough required in its development (36). The volume or actual space that an escape system displaces is another parameter that should be minimized. If an escape system is located inside the space station, the space that would be used for scientific equipment and other life support systems is decreased. An additional concern noted by NASA personnel is the ability to maintain the center of gravity on board the space station (25).

It is important to maintain the minimum gravity level necessary for various experiments that will be accomplished on the space station.

Another important factor is the speed at which the escape mechanism can be operated. The escape system should have minimal access time. A device that is quick to get into is more capable in short notice emergencies. The device should also be able to quickly separate and safely clear the station after departure.

In the case where injured personnel were to require an escape mechanism the device would need to minimize "G" forces on the crew member (10;39).

An escape device kept for long periods of time requires a long shelf life. Along with the need for a long shelf life of the device, minimal maintenance and upkeep time is a desired trait (39). This assures a device that will work when necessary but is not a continual maintenance problem that detracts from the primary mission of the space station. Alternative usage for the escape mechanism is also desired (42). This, in some way, may ease the economic impact of such a device. An example of alternative usage is the airline floatation device that just happens to be a seat cushion.

Several other concerns that must be considered arise during and after the re-entry sequence of an escape device. Prior to and during the re-entry phase an escape device must be able to adjust and make course corrections due to weather or for other safety reasons. A trade-off therefore develops between a manual override system for use by fully functioning crew members on the escape system versus the full autonomy that may be required in situations discussed earlier. Another option in

this case would be total ground control throughout the re-entry sequence. Additional objectives for an effective space escape system deal with final recovery on earth. An escape device must be able to survive land or water impact. Two-thirds of the earth's surface is covered with water requiring the device to be able to float (6). Delayed recovery efforts by ground personnel would require the escaping crew to have sufficient provisions for survival until rescued. In addition, communication and locating devices are both necessary for the safety and well-being of the escaping astronauts.

Measures of Effectiveness

The purpose of this chapter is to set the foundation for the systems analysis process in chapter three. To accomplish this, the above section outlined areas of concern which are the objectives to be attained by a potential space station emergency escape device. To compare alternative systems that may be the solution to the problem you must be able to measure the attainment of the objectives. The measures of effectiveness accomplish this.

The ideal goal in developing measures of effectiveness is to be as objective as possible. This analysis will, however, contain some degree of subjectivity as is common in similar research efforts. In table 2.1, the major objectives are shown with their corresponding measures of effectiveness. Note that for some of the objectives the measure of effectiveness is either a subjective analysis or a yes or no response.

For the objective of low technology risk the measure of effectiveness is a subjective three level feasibility scale. The highest level

corresponds to the escape device requiring current technology. The mid level scale is for a device that requires some degree of advanced technology and, therefore, medium risk. The lowest level corresponds to an escape device that requires a major technological break through for its development.

The objective of simplicity is measured by a three level scale based on the tasks required by the escaping crew. For the highest level scale the escape system is fully autonomous. For the mid-level, the escaping crew is required to activate thrusters and retro-rockets or other simple controls. For the lowest level at least one crew-member using the escape device is required to be a pilot-astronaut.

Several measures of effectiveness are straightforward. The objective of minimizing the weight(mass) of the escape device is measured in kilograms. The measure of effectiveness for minimal cost is the total acquisition cost (design, development, and hardware) in 1986 dollars. The measure of effectiveness for minimal volume is the number of cubic meters displaced by the stored escape device.

A major objective, minimize time to enter and escape, is measured in hours, minutes, and seconds. The time to enter the escape device begins when the decision is made to egress the space station. The clock ends at the moment when all personnel inside the escape system are clear of the space station.

The objective to minimize G forces is measured by the peak re-entry acceleration of the escape module in Gs. One G corresponds to the acceleration of an object at sea level due to the gravitational pull of the earth.

The objective of alternative use is measured by the number of different ways the escape device can be used other than for emergency escape. This is based on general alternative uses discussed in the next chapter.

A three level scale is used as the measure of effectiveness for the objective of having controllability options. The highest level corresponds to a vehicle capable of atmospheric flight and major course corrections. The middle level corresponds to a smaller degree of control and the lowest level corresponds to the device having no controlability options.

The measure of effectiveness for the objective of land or water recoverability is a two level yes/no scale. The higher level corresponds to a device that can survive land or water impact. The lower level corresponds to a device that can recover only in one of the two possibilities.

The measures of effectiveness discussed above encompass many major concerns in evaluating space escape devices. Some objectives previously mentioned are not listed in table 2.1 and the corresponding measures of effectiveness for those objectives are not considered on this analysis. The objective of long shelf life and minimal up keep are both such examples. Neither are included directly in this analysis, however, they both relate to the reliability and low technology objective and also the objective of simplicity.

In the event of an actual space escape situation our earth bound facilities would be readily tracking and locating an escape device. These efforts, combined with our current world wide distribution of military forces capable of recovery efforts, limit the need for excessive storage of

supplies and provisions for lengthy earthbound stays after de-orbit. This current recovery potential also eliminated the need to compare escape modules in terms of their communication and locating equipment. Any escape device will have a means of communication and todays transponders are small and relatively inexpensive.

Another area not used in comparing alternatives is the time to de-orbit. The actual time to get from the point of being clear of the space station to being on the surface of the earth does not, for this analysis, pose any level of significance. Several factors, including available recovery equipment, area of recovery, condition of astronauts, and weather will effect this time measurement. The overriding concern, in terms of time, is the time it takes for all escaping astronauts to enter, activate, and clear the escape module from the space station.

Another objective not included in table 2.1 is the variety of catastrophies accomodated. The time to activate and use an escape system indirectly determines the variety of problems that the escape device can accomodate. The shorter the time required to escape the more likely the crew will survive a variety of catastrophes.

The basis for comparison of alternative escape systems is now defined by the objectives and measures of effectiveness. It has been noted that the space station is a large and unique space complex with several crew members on-board for extended periods. The potential hazards to crew safety have been discussed and the basic needs and concerns for their safety generated the objectives above. The next chapter introduces the alternatives to be examined. From the relative values of the measures of

effectiveness for each of the alternatives, conclusions and recommendations on the best escape mechanism(s) will be made for two different manning scenarios.

TABLE 2.1

OBJECTIVES AND CORRESPONDING MEASURES OF EFFECTIVENESS

FOR SPACE STATION EMERGENCY ESCAPE SYSTEM

Objective	Measure of Effectiveness
A) Low Technological Risk	Degree of technical feasibility (current, advanced, major breakthrough)
B) Simplicity	Degree of Astronaut tasks (Little or none, medium, Pilot Astronaut required)
C) Minimum Weight	Mass in Kilograms
D) Minimal Cost	Design Development, Test & Evaluation, and Hardware cost in 1986 dollars
E) Minimal Volume	Volume displaced in Cubic Meters
F) Quick to Enter & Escape	Time in Hours and Minutes
G) Minimize G Forces	Minimize Re-Entry Acceleration in G's
H) Alternative Uses	Number of Alternative Uses
I) Controllability	Degree of Controllability (high, medium, low)
J) Land or Water Recoverable	Yes/No

III. Analysis Of Alternatives

Introduction

The purpose of this chapter is twofold. First, the alternative emergency escape systems that can be used on the space station are introduced. In the first section, alternative escape systems are discussed in terms of their generic operation for use in space. Drawings and support data on physical characteristics are included for each alternative. Secondly, alternatives are analyzed in terms of the objectives outlined in chapter II. The values of the measures of effectiveness are determined in the various categories corresponding to the operating objectives. This is accomplished for two different manning scenarios which are outlined in the analysis section. The chapter concludes with a summary of tabulated results of the analysis for both scenarios.

Alternatives

Emergency escape devices, as defined by the scope of this paper, are contained inside or attached to the outside of the space station. These mechanisms incorporate unique, and for the most part, untested ideas involving rigid structures, inflatable compartments, ejection seats, flexible ablative shields, and new space suit designs. This section will outline the alternatives without regard to similarities in function and design. Due to lack of information not all alternatives will be analyzed. In some cases the similarities are so close that a single generic representation of two or more similar alternatives will be analyzed in lieu of several individual evaluations.

<u>Expandable Disk Re-entry Module</u> (see Fig. 3.1) (27). This emergency escape device is an inflatable module that is attached to the exterior of the space station. Entry to the module is made through a rigid entry section. The majority of the structure is an inflatable nickel-chromium alloy metal fabric made from fine filaments. The exterior surface of the metal fabric is coated with a silicone elastomer ablative material for re-entry protection. The Expandable Disc Re-entry Module has two designs, a one-man and a three-man capacity system. The expandable structure can be inflated after the space station is erected or prior to emergency escape. Inflating the structure prior to need, however, risks the danger of meteorite or debris penetration. The inflated metal fabric, which is impregnated with a resin compound, becomes rigid by gas catalysis of the resin compound. The torus portion of the module (see fig 3.1)is inflated first followed by the remainder of the structure. After inflation of the exterior of the module the crew couch and cabin walls are formed by a rigidizing polyurethane foam that provides insulation and structural support. Once foaming and inflation are complete, the crew enters the module and straps into the foam formed contoured crew couch. The module contains life support equipment designed for space suits which the crew must don prior to entry. The module separates from the space station when the crew activates small thrusters. De-orbit parameters are selected by the crew and, after performing stablizing maneuvers, retro rockets are fired for re-entry. A lifting re-entry is accomplished with the module at a 60° angle of attack. At the necessary altitude stabilization of the module takes place by a drogue chute. Recovery is accomplished by a

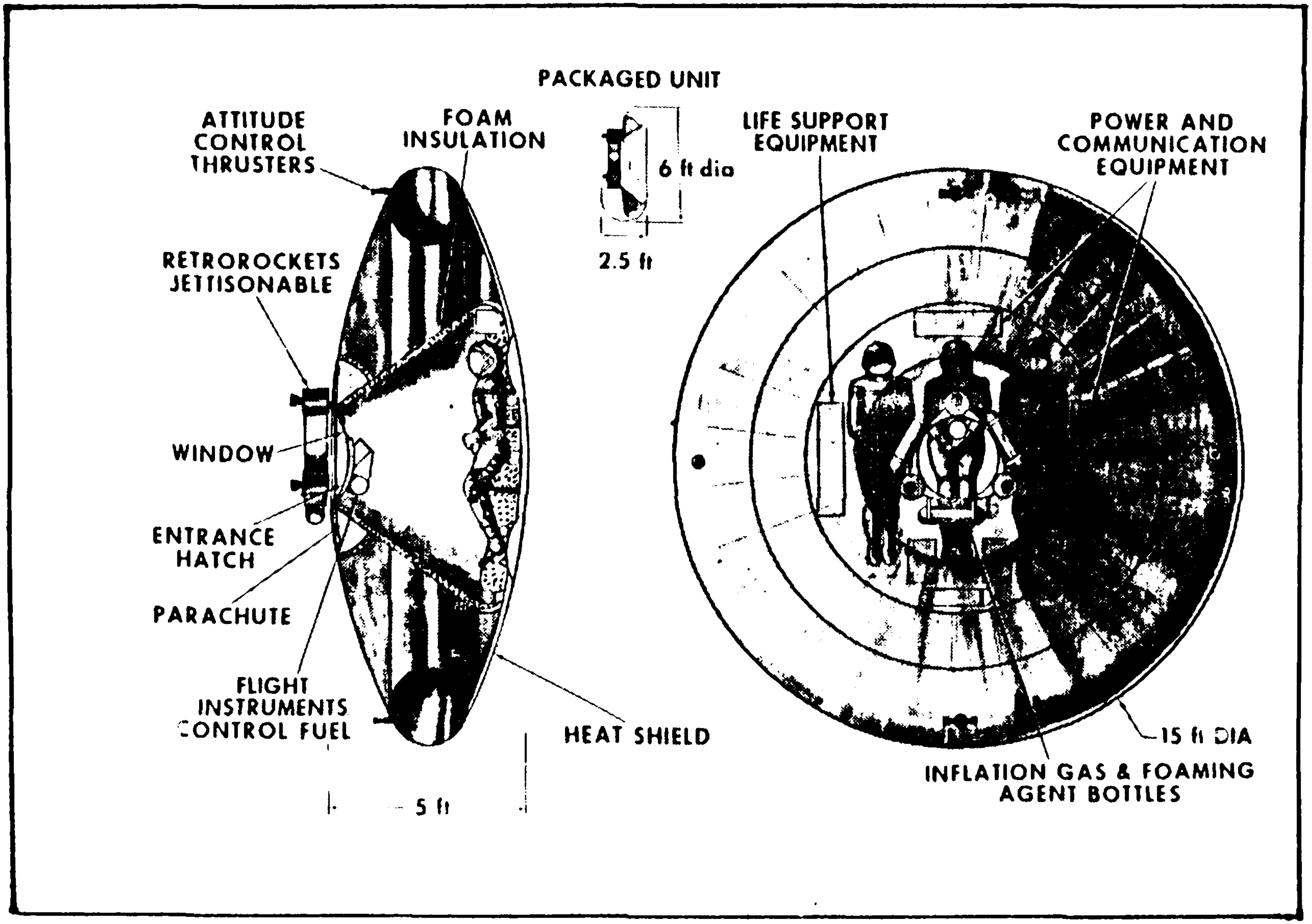


Fig 3.1 Expandable Disk Re-entry Module (27:16)

parachute and deployment of a landing bag. Water or land impact is possible, with the inflated frame and foam-formed interior supplying impact attenuation and floatation.

<u>Maneuverable Entry Research Vehicle (MERV)</u> (see Fig. 3.2) (16;17). MERV is a flight research vehicle being examined by the Air Force as a future operational testing platform for the study of advanced aeromechanics, flight controls, structures, thermal protective systems, propulsion, guidance and other aerospace related concerns for the 1990's. In this study it is proposed as an escape vehicle attached to the exterior of the space station. MERV is a completely rigid high performance vehicle capable of atmospheric propulsion as well as space propulsion. For this analysis all atmospheric propulsion engines are removed. Three escaping crew members could use this device with one acting as pilot and the others riding in the payload bay. The MERV life support systems allow a shirt-sleeve environment where no space suits are required. In emergency situations requiring escape the crew enters MERV through a connecting node attached to the space station. After entering the device, the pilot initiates separation from the space station by various thrusting maneuvers. Re-entry is similar to that of the space shuttle, with no powered flight possible after entering the atmosphere.

<u>Emergency Astronaut Re-entry Parachute System</u> (see Fig. 3.3) (50). This escape proposal is similar to that used in high performance military aircraft. The simple operation is based on a single crew member escaping from the space station in an ejection seat. After ejection a 21 meter

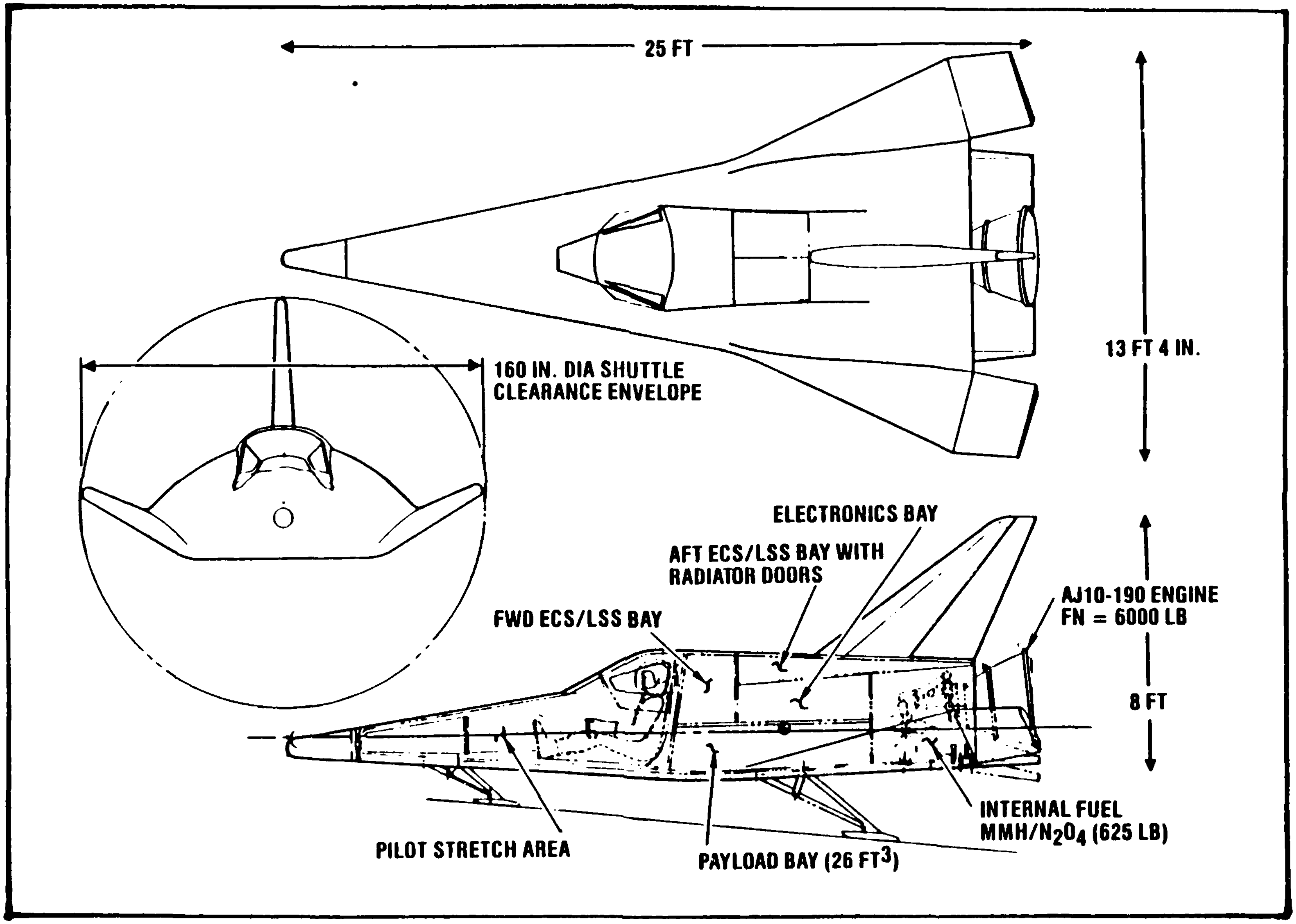


Fig 3.2 Maneuverable Entry Research Vehicle (17:12)

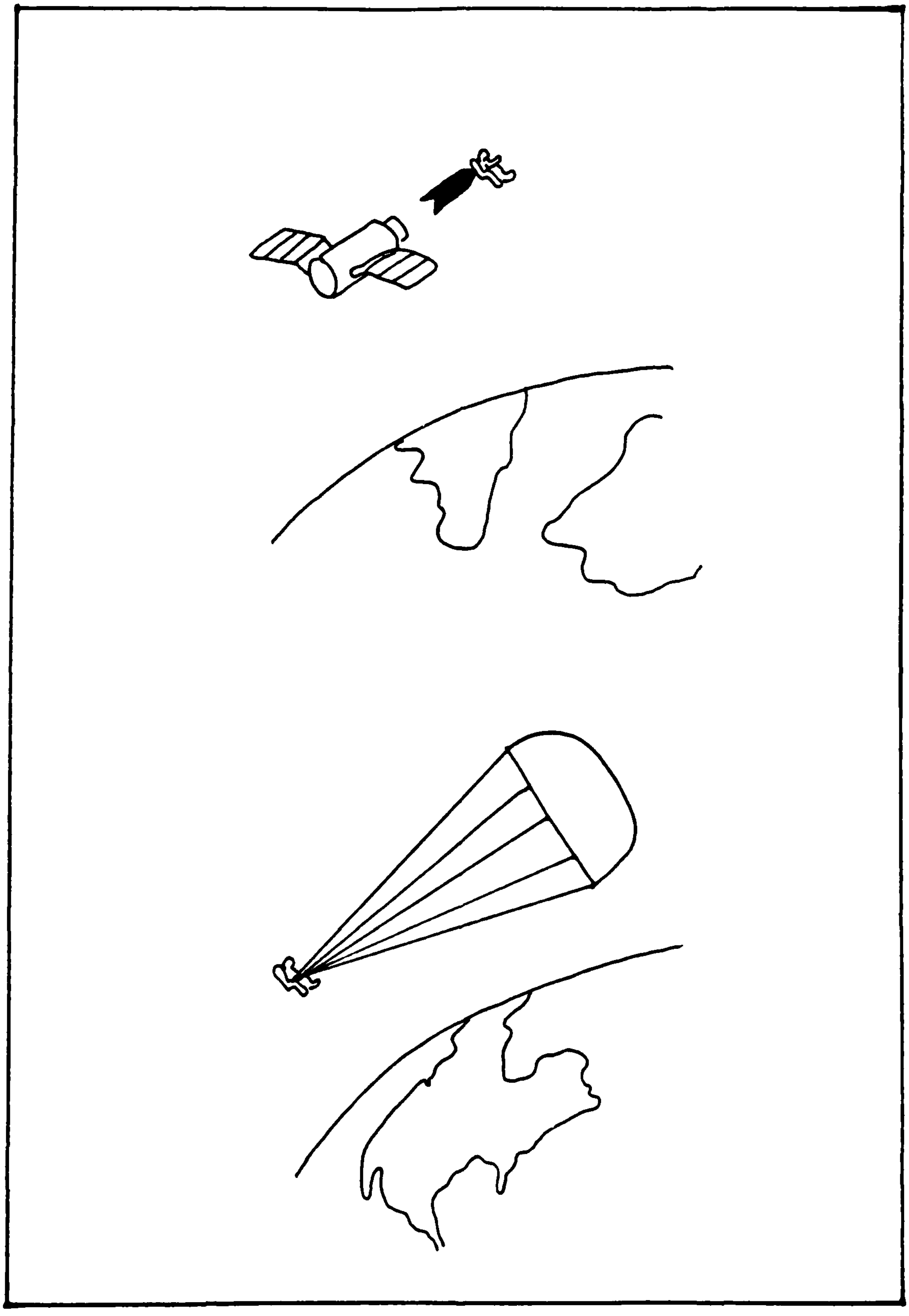


Fig 3.3 Emergency Astronaut Re-entry Parachute Systems Operation (33:9)

diameter parachute is deployed and automatically springs open to its full diameter and full extension. The astronaut remains in the contoured ejection seat attached to the parachute. Deceleration due to atmospheric drag and the gravitational pull of the earth then reduces the altitude of the astronaut and parachute system. Shortly after enacting these procedures, the astronaut will pass through the difficult process of re-entering the atmosphere.

A specialized space suit and parachute system is employed to survive the effects of re-entry. After the re-entry effects are over, the astronaut lands in the typical descent of a parachute landing.

Inflatable Orbital Escape Device (see Fig. 3.4) (15:226). This unique inflatable escape device is a one-man unit that could be stored in a small interior compartment of the space station. The device, stored in a canister, is carried out of the space station through an air lock with the crew member in an EVA space suit. Once both the astronaut and the canister are outside the space station the escape device is deployed. It includes a spherical bag that the astronaut enters. The bag is composed of an inner and an outer bladder that are inflated after the astronaut enters the device. Thrust is provided by venting pressure suit oxygen and carbon dioxide to a hand held thrusting unit. A small window in the inflated structure allows for visual orientation for retro-fire for de-orbit. The internal bladder, once inflated, supports the crew member in a fetal position and maintains the spherical contour of the device. The astronaut re-enters in this inflated ball. After passing through the critical

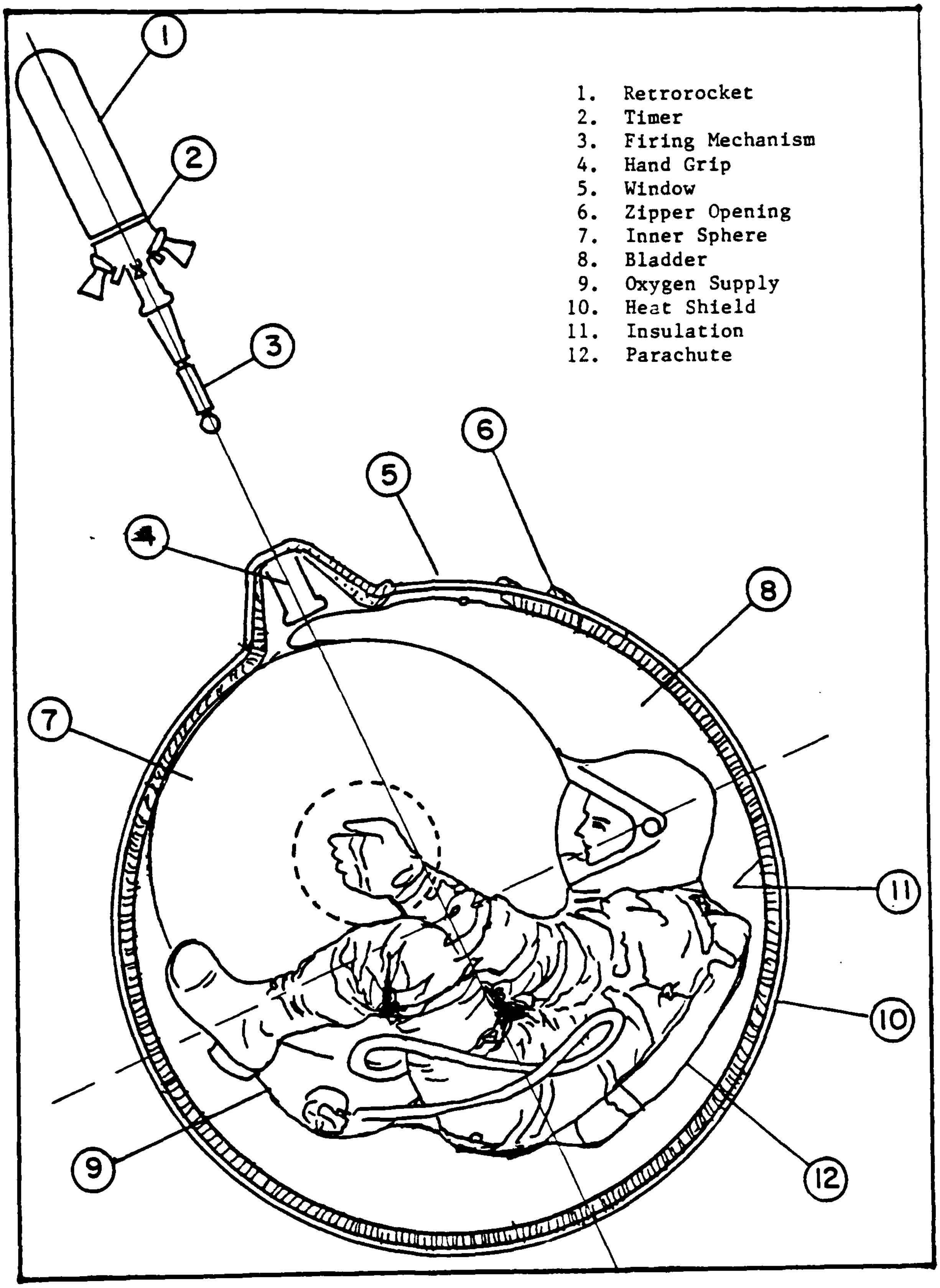


Fig 3.4 Inflatable Orbital Escape Device (21:10)

heating stages of re-entry, the outer bladder cools and deflates. This allows the crew member to unzip an interior enclosure flap and ultimately descend by parachute.

Manned Orbital Space Escape System (MOSES) (see Fig. 3.5,3.6) (28;29;30;31) MOSES is based upon General Electrics' Satellite Recovery Vehicle used to recover information from earth orbiting satellites. It is a blunt-nosed rigid escape device that is externally attached to the space station. Various designs allow for 1, 2, 3, or 4-man configurations capable of re-entry. The primary structure contains the crew compartment enclosed in a recovery capsule. Covering the recovery capsule is the forebody re-entry heat shield. Escaping crew members enter MOSES through an air lock attached to the space station. Each crew member require a pressurized space suit and a self contained life support system. Disconnection and thrust away from the space station can be activated by escaping crew members, remaining space station personnel, or by ground personnel. The MOSES device contains the necessary communications equipment, beacons, and provisions enabling selective de-orbit.
A major goal in the development of this system is full autonomy. Attitude control and sensing equipment is designed so that separation from the space station in an uncontrolled manner is readily and automatically rectified for proper positioning prior to automatic retro-fire. An automatic three axis attitude sensing and control system accomplishes this feat. After retro-fire the escape module initiates terminal descent procedures by deploying a drogue chute which, in combination with pyrotechnic devices separates the capsule from the forebody. After a short period of

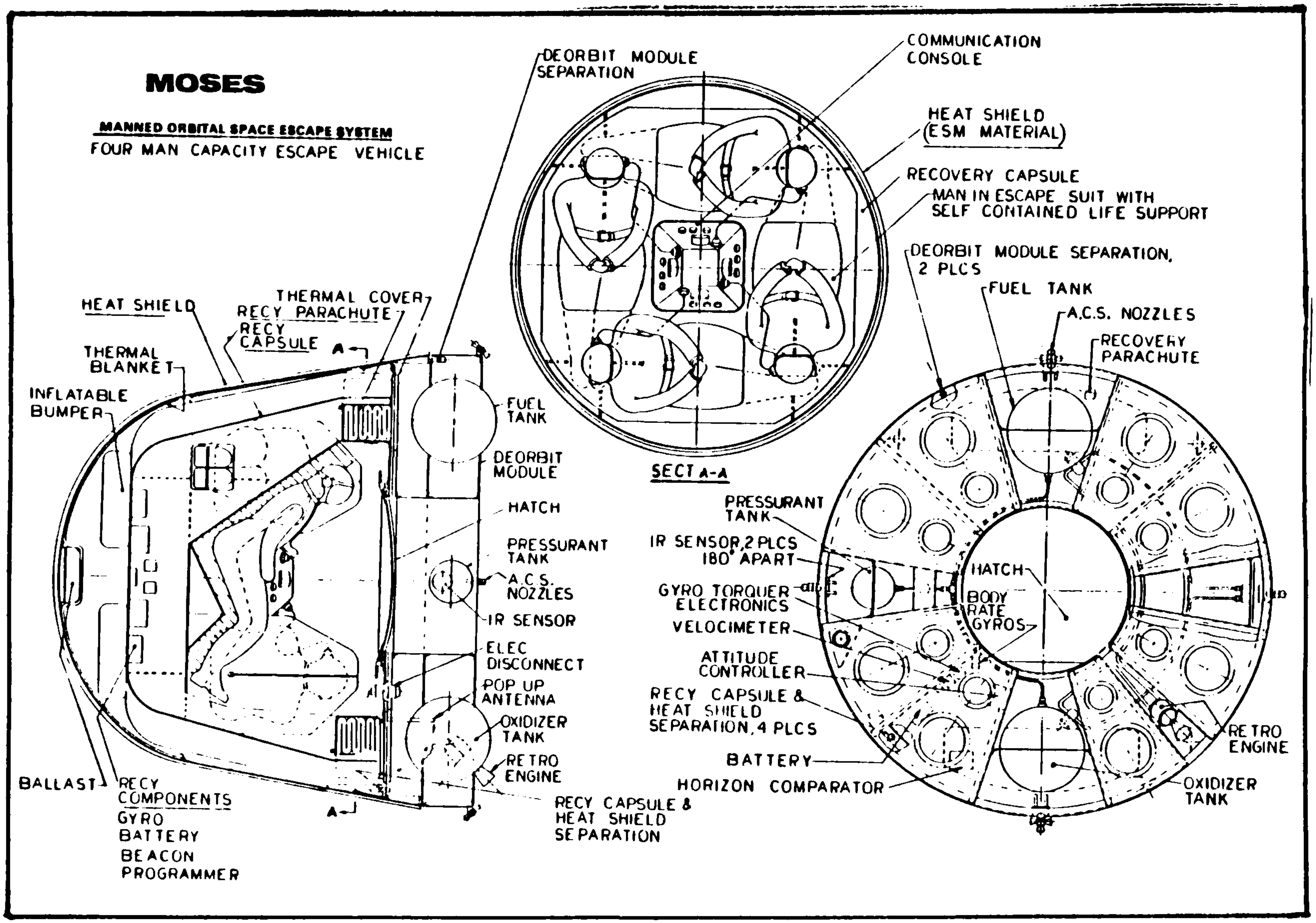


Fig 3.5 Manned Orbital Space Escape System (MOSES) (31:4)

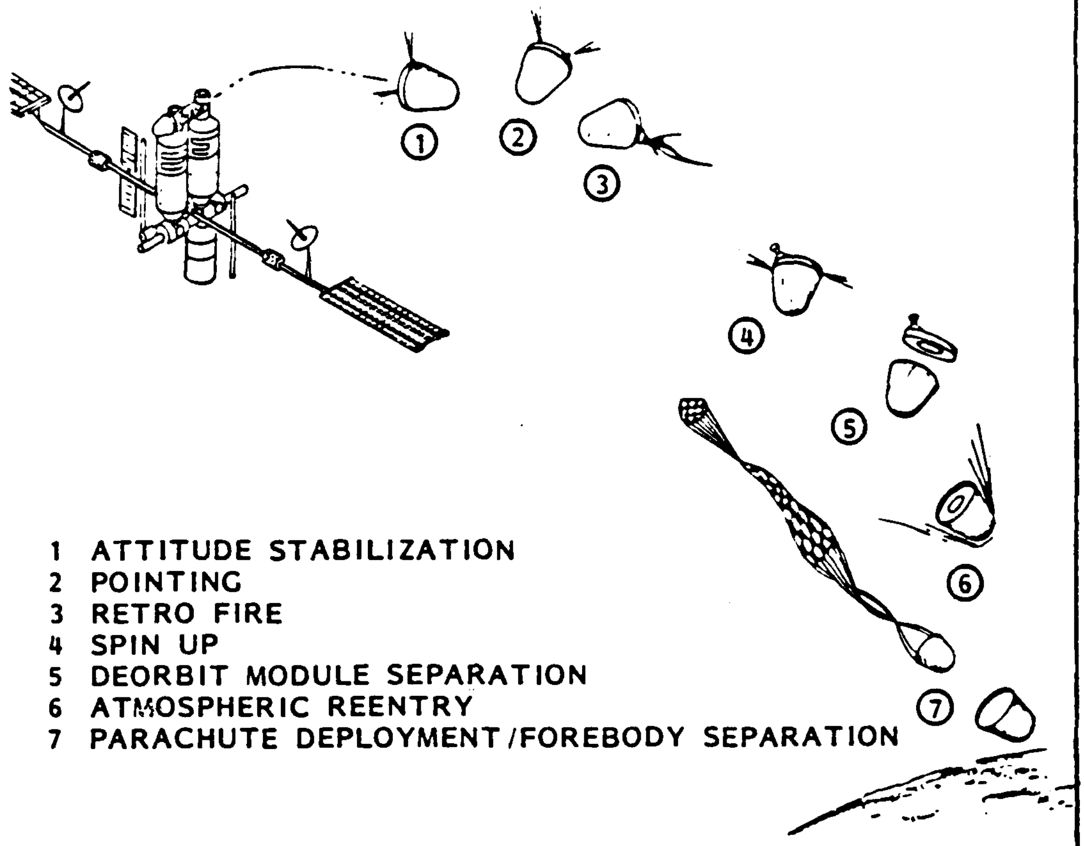


Fig 3.6 MOSES Operating Sequence (31:9)

deceleration the main parachute is deployed and an inflatable shock attenuation system is activated for land recovery. While ballast design and an impact attenuation bag allows for floatation in case of water landings, the basic design is for land recovery. General Electric has also evaluated the possibility of using an advanced recovery system that uses a rectangular gliding parachute system, instead of the standard round parachute. This advanced recovery system has an automated homing device with manual override controls for use by the escaping crew members. This system has several benefits including weight savings, less volume, better maneuverability, and obstacle avoidance prior to touchdown.

Paracone (see Fig. 3.7) (23). The Paracone is an inflatable space escape system similar to the Expandable Disk Re-Entry Module except that the inflatable cone formed after activation is open at the top and no parachute recovery system is utilized. Like the Expandable Disk the Paracone system is incorporated into a one-man ejection seat that separates from the side of the space station. The escaping astronaut is in a complete EVA space suit that includes a full life support system. After ejecting, and at a safe distance from the space station, the escaping crew member actuates a set of small attitude control jets to stabilize the ejection seat. Once stabilized, the astronaut rotates a small, solid propellant retro-rocket that is stored in the ejection seat into proper position for firing. After firing the retro rocket the Paracone, which is stored in the back portion of the ejection seat inflates around all sides of the seat and astronaut except the top. The large inflated cone structure absorbs the heat of re-entry and slows the astronaut and entire

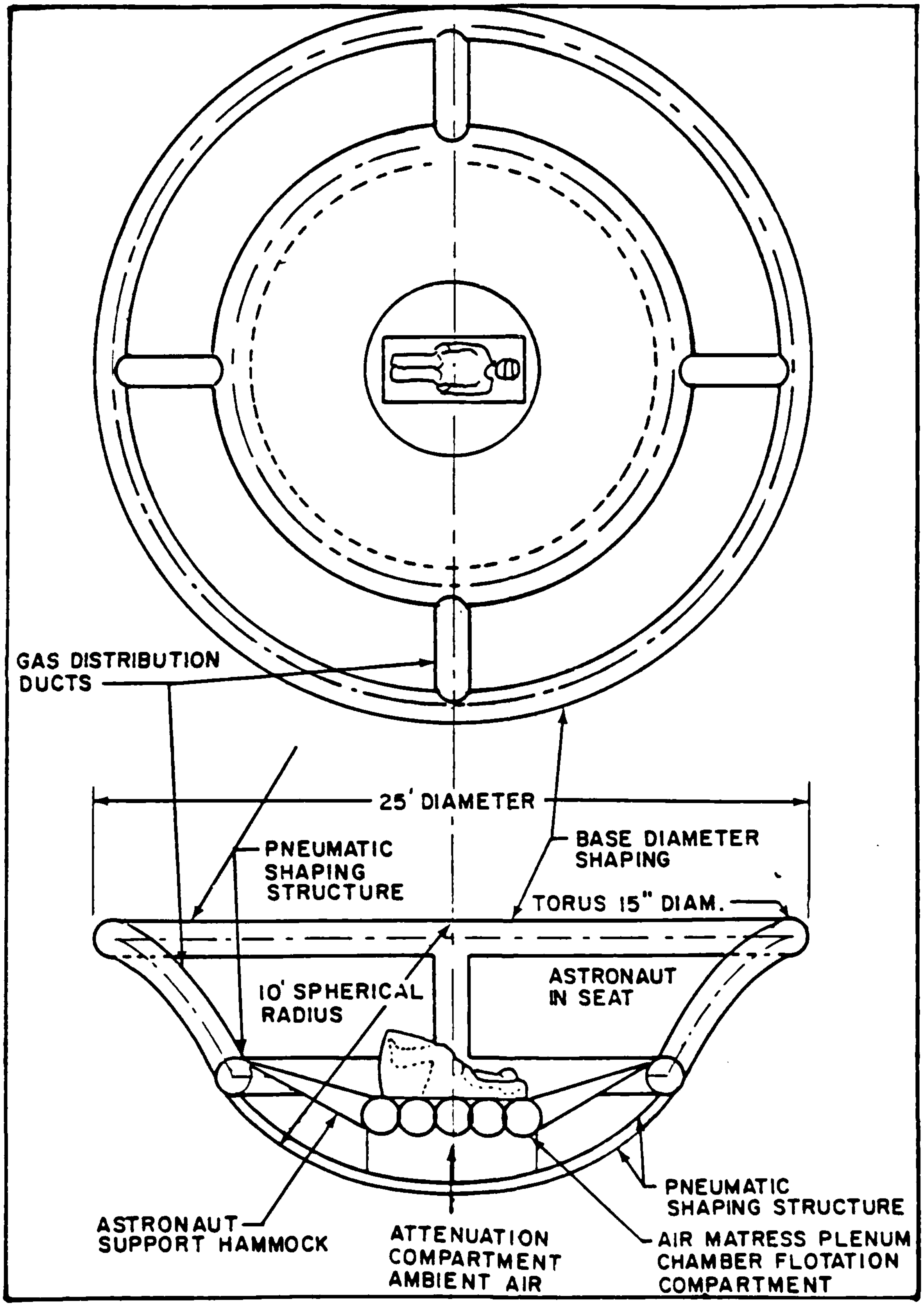


Fig 3.7 Paracone Escape Device (1)

rescue system to an impact velocity of approximately 32 kilometers per hour. Impact atentuation is an ambient air compartment approximately 1 meter below an inflated air mattress that supports the astronaut and ejection seat in "hammock" style. Contained as part of the system is a survival pack with three days worth of provisions, communications beacons, and a three hour life support unit for attaching to the space suit. The Paracone is designed to withstand land impact and will float adequately for water impact and recovery.

Hermes Minishuttle (see Fig. 3.8) (16:46;13:17). The French Space Agency CNES is currently evaluating development of a minishuttle similar to the U.S. space shuttle but scaled down to approximately 18 meters in length with a 10.4 meter wing span. As a potential escape system the Hermes would be attached to the space station at docking ports designed for the U.S. space shuttle (see fig. 2.4). The Hermes accomodates four crew members in the cockpit and has a small cargo bay in the center fuselage. Modifications to this cargo bay could allow for additional crew members for an increased escape capacity. In an escape scenario the crew members would board the Hermes through the docking port. No space suits are required in the pressurized vehicle. After boarding, the pilot activates required thrust rockets to separate from the space station. Re-entry is accomplished like the U.S. space shuttle. Stabilization and re-entry procedures would all be complex maneuvers accomplished by the crew. The conceptual design calls for land recovery on prepared surfaces similar recovery of the U.S. space shuttle.

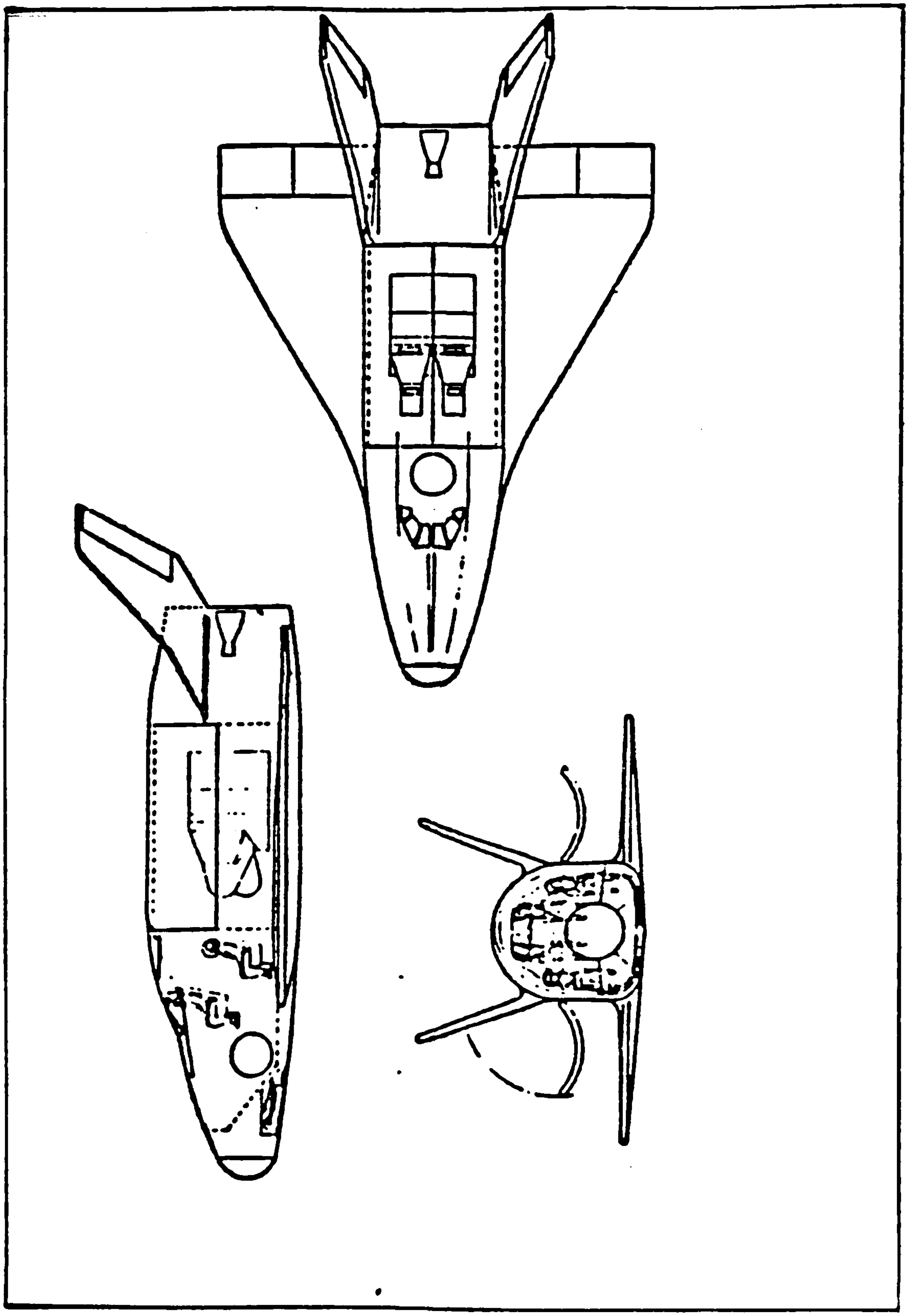


Fig 3.8 Hermes Mini Shuttle (13:17)

MOOSE (Man Out Of Space Easiest) (see Fig. 3.9, 3.10) (37). This space escape system, and the next two systems, evolved from an early General Electric space escape study that analyzed various re-entry escape techniques. MOOSE, also called Satellite Life Jacket, was designed so that a single escaping crew member could survive in the harsh environment of space for short periods until re-entry through the earth's atmosphere. MOOSE is similar to the Inflatable Orbital Escape Device discussed earlier. When it comes time to escape from the space station the crew member dons an EVA space suit with the entire suit enclosed in a plastic bag covering. Attached to the plastic covering are foaming plastic and mixer dispensers. The escaping crew member also has a hand-held retro rocket for de-orbit. For escape from the space station the crew member would egress the station via an air lock used for typical EVA scenarios. Once outside of the space station the crew member visually orients himself to the earth. Using an optical siting instrument, or possibly an IR sensor for dark side landings, the crew member measures altitude and direction of flight. Using this information and precalculated range tables, the crew member aims and fires the retro rocket for proper re-entry. An updated version of MOOSE uses a micro-computer to accomplish all calculations mentioned above. After retro rocket fire, cold jets are then used to position the escaping crew member properly for re-entry. The plastic covering surrounding the astronaut is then inflated with various density foam plastic. Very dense plastic foam of 50 lb/ft^3 forms the ablative shield, a less dense of 5 lb/ft^3 forms the afterbody and low density foam of 1 lb/ft^3 supports the man inside the vehicle. During re-entry the dense foam ablates, protecting the crew member from high temperatures. The low density foam is designed to act as

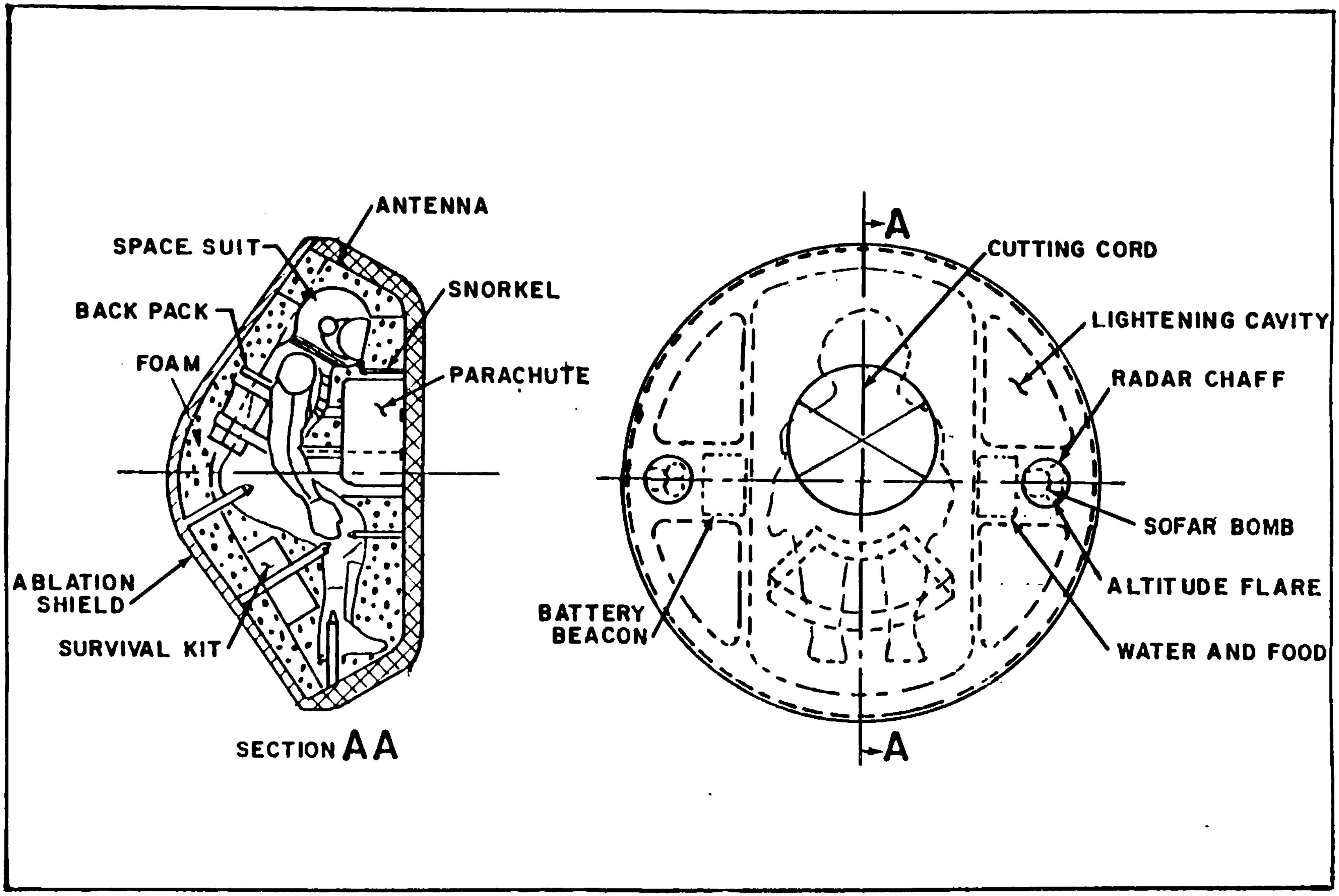


Fig 3.9 MOOSE (37:39)

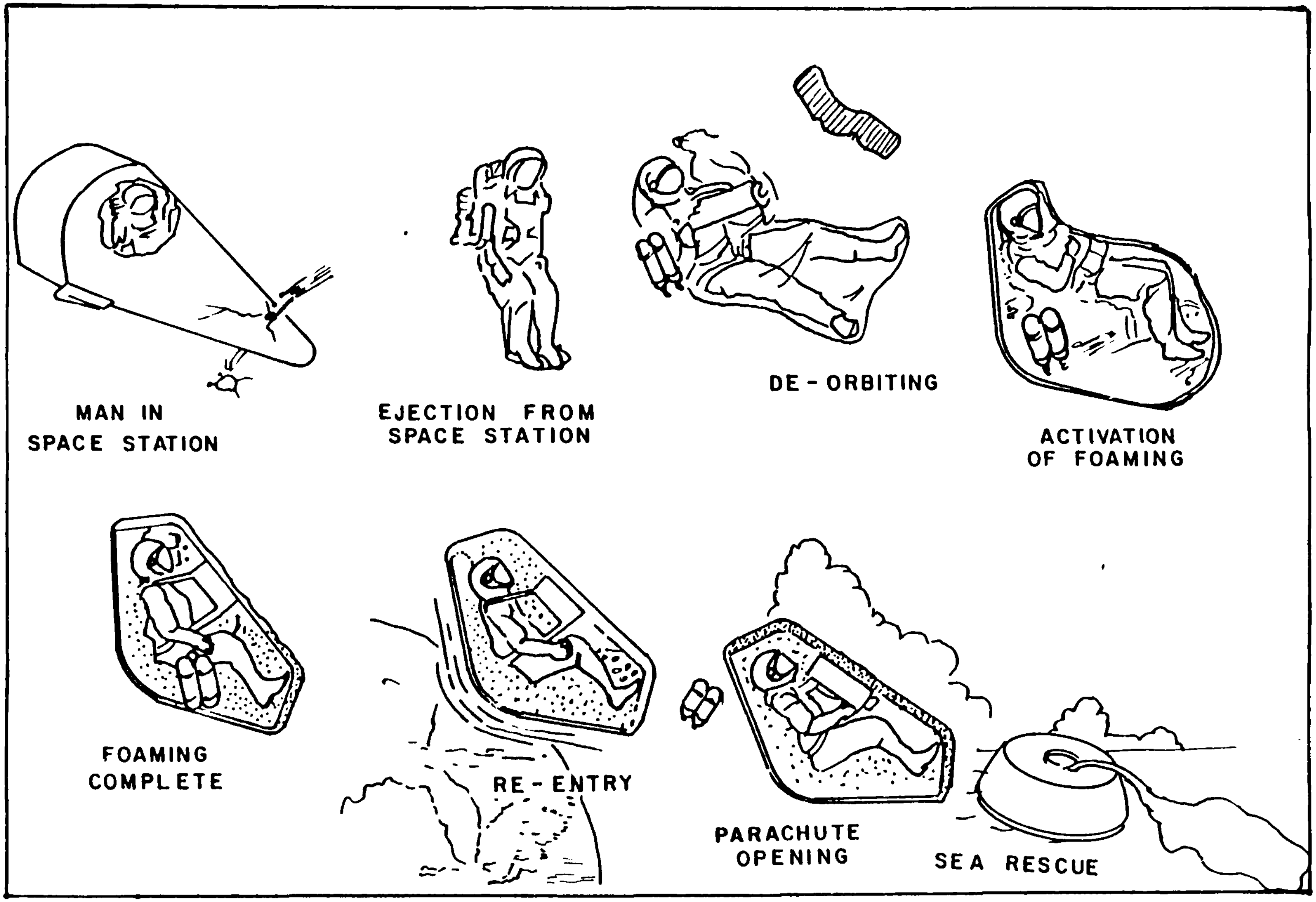


Fig 3.10 MOOSE Operating Sequence (37:40)

a cushion against deceleration forces caused by re-entry. At approximately 9 kilometers a parachute is deployed. The force of this deployment pulls cords that cut the lightest foam from around the escaping crew members arms and hands. This enables the Astronaut to free himself after landing.

MOOSE is designed to withstand land or water impact. In case of water impact, MOOSE is able to float and can be used as a raft. Included in the design is a survival kit in case of delayed recovery efforts of earthbound personnel. MOOSE uses three locating aides which include expelled radar chaff following maximum re-entry heating, a high intensity flare fired for visual sighting, and sofar bombs that send distress signals through water in case of water recovery.

<u>Satellite Life Raft</u> (see Fig. 3.11, 3.12) (37). This system is a one-man capacity device similar in re-entry shape to MOOSE but completely rigid in structure. For use on the space station the satellite life raft is attached directly to the wall of the one of the modules or, as an alternate location, to an air lock for direct access by an escaping crew member. The rigid vehicle is designed with a 1.3 millimeter thick fiberglass liner protected by a nylon reinforced phenolic plastic ablation shield 1.9 millimeter thick and a 0.6 millimeter thick honey-combed aluminum core fiberglass after-body that composes the remainder of the structure.

During typical operations with the Satellite Life Ratt mounted on the wall of a space station module, the heat shield would protrude from the space station and the entrance hatch would be open to the inside of the space station module. When emergency escape is required the crew member

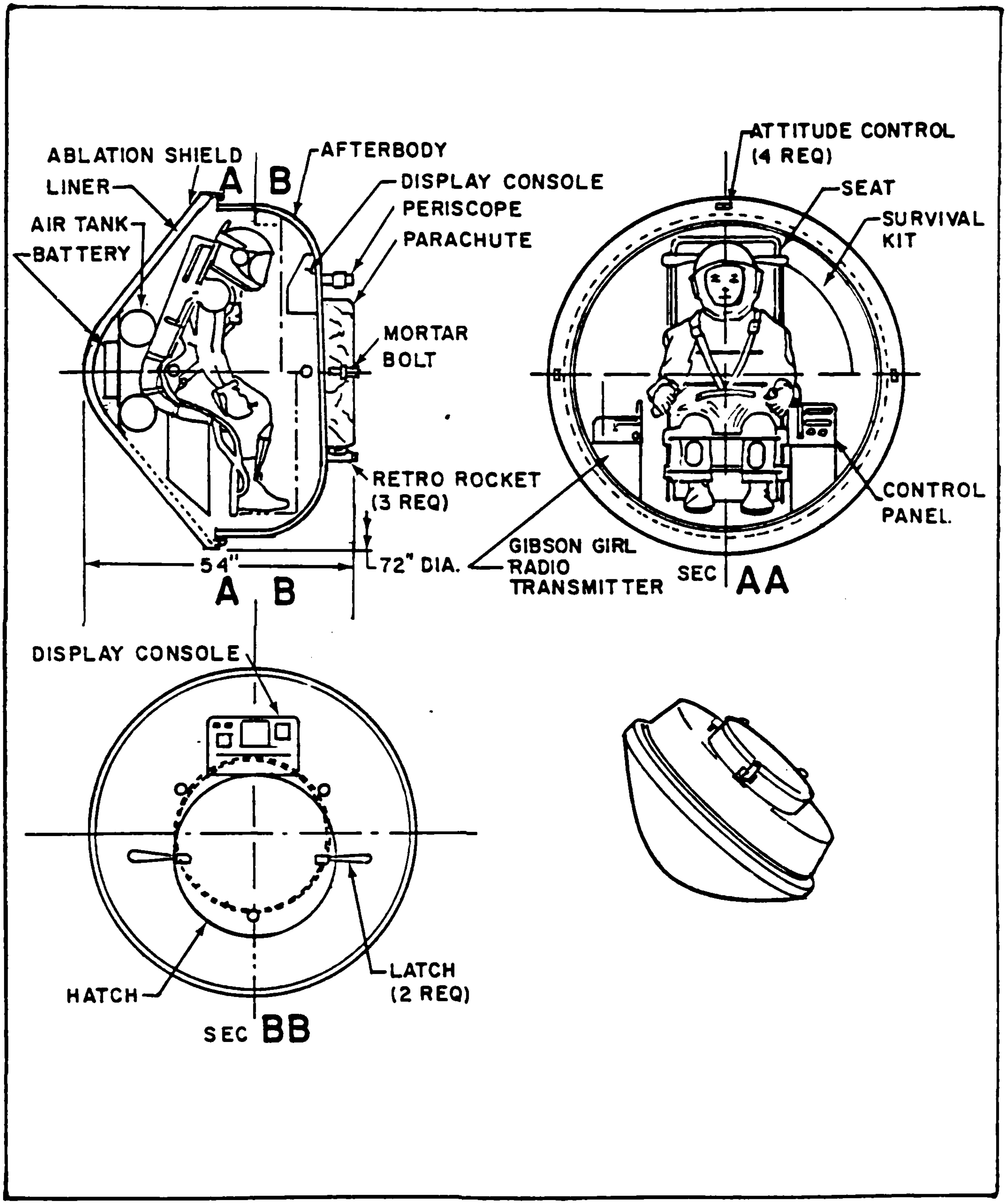


Fig 3.11 Satellite Life Raft (37:43)

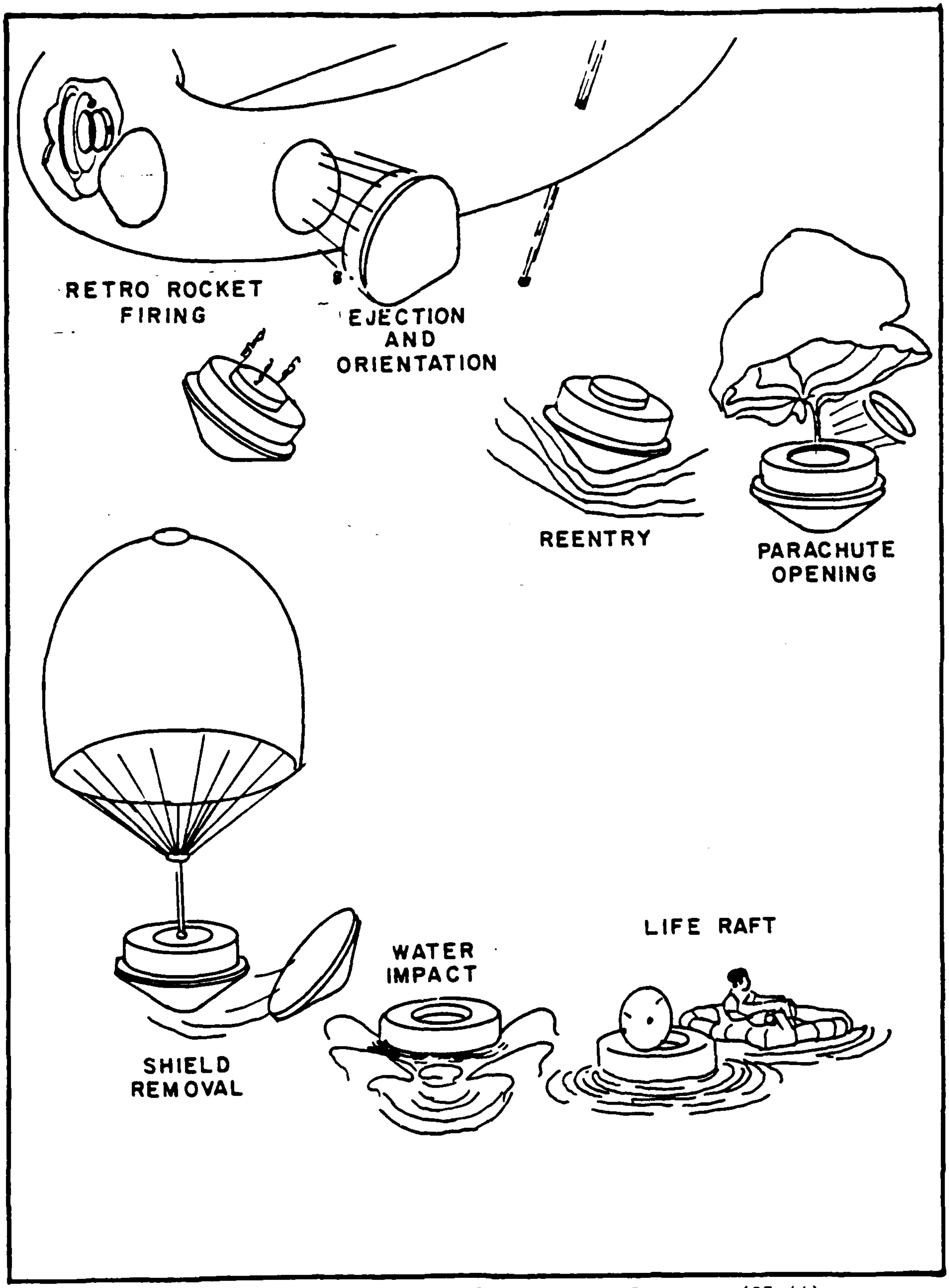


Fig 3.12 Satellite Life Raft Operating Sequence (37:44)

would don a space suit and enter the Satellite Life Raft. The crew member would secure the hatch and then disengage airtight seals and clamps that hold the Satellite Life Raft to the space station. The clamps and seals are explosively or magnetically terminated depending on the type used. A spring system ejects the escape capsule clear of the space station. The crew member then secures himself in a nylon webbed, aluminum framed seat. The Satellite Life Raft has a periscope with a 180° lens that has a scribed display face used for determining proper orientation for de-orbit. The escaping crew member controls attitude jets to position the satellite life raft for proper retro rocket firing. This is accomplished by visually referencing the earth on scribed circles on the periscope. Once the proper position is achieved the crew member fires the retro rockets for re-entry into the earths atmosphere.

The ablative heat shield that insulates and protects the escaping crew member is jettisoned from the Satellite Life Raft after a recovery parachute is automatically deployed at approximately 9 kilometers. Removal of the heat shield avoids heat transfer that would increase inside temperature of the capsule. The parachute system sufficiently slows the escape capsule to allow for land or water impact. The Satellite Life Raft is designed to float in case of a water landing and includes a survival kit which contains a rubber life raft in the event it becomes necessary to abandon the escape capsule. The survival kit also includes provisions for surviving in any harsh earth environment. The Satellite Life Raft includes signalling and location aids similar to MOOSE. Signaling procedures, which are actuated sequentially include flares, radio beacon, and sofar bombs for water impacts. A hand-powered "Gibson Girl" radio transmitter provides

rescue personnel with a homing signal. This type of signalling device could be upgraded to an automatic self-contained homing device similar to those used on modern aircraft.

Satellite Life Boat (see Fig. 3.13, 3.14) (37). This escape system is a rigid three-man device designed to be attached to the walls of the space station like the Satellite Life Raft. Access to the Satellite Life Boat is also the same. The operational procedures carried out are identical to the life raft procedures from separation to re-entry. The Satellite Life Boat has an aerodynamic shape that allows one of the escaping crew members, a pilot astronaut, to fly the vehicle to a suitable landing point. The location aids used in the Satellite Life Raft are all used in the Satellite Life Boat. On approach to the landing area a parachute is deployed and landing is made vertically. The entire Satellite Life Boat escape system is designed to float, in case of a water landing, with the nose portion protruding out of the water. The nose section can be jettisoned, with the crew safely inside the rear section of the escape capsule. The lifeboat escape system includes all of the safety and survival provisions as the life raft escape device.

Egress (see Fig. 3.15) (36:70). The Egress escape concept, developed by Martin Marietta, incorporates a single person ejection seat system similar to the Paracone. Available information is limited on this device, however it appears that an escaping astronaut enters a seat system that is part of the Egress escape module and then activates a rigid movable canopy that fully encloses the crew member. After enclosure, the astronaut and

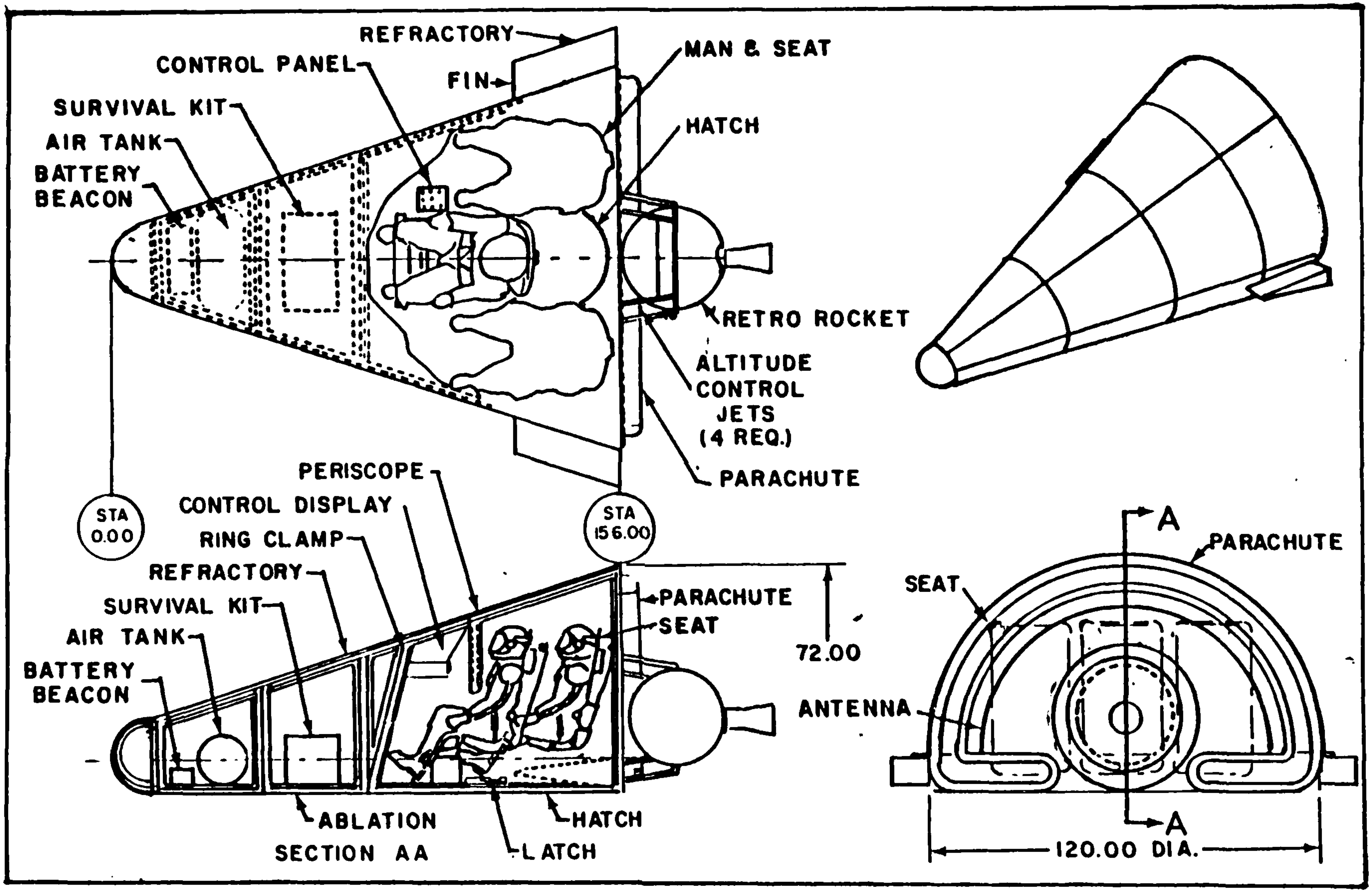


Fig 3.13 Satellite Life Boat (37:48)

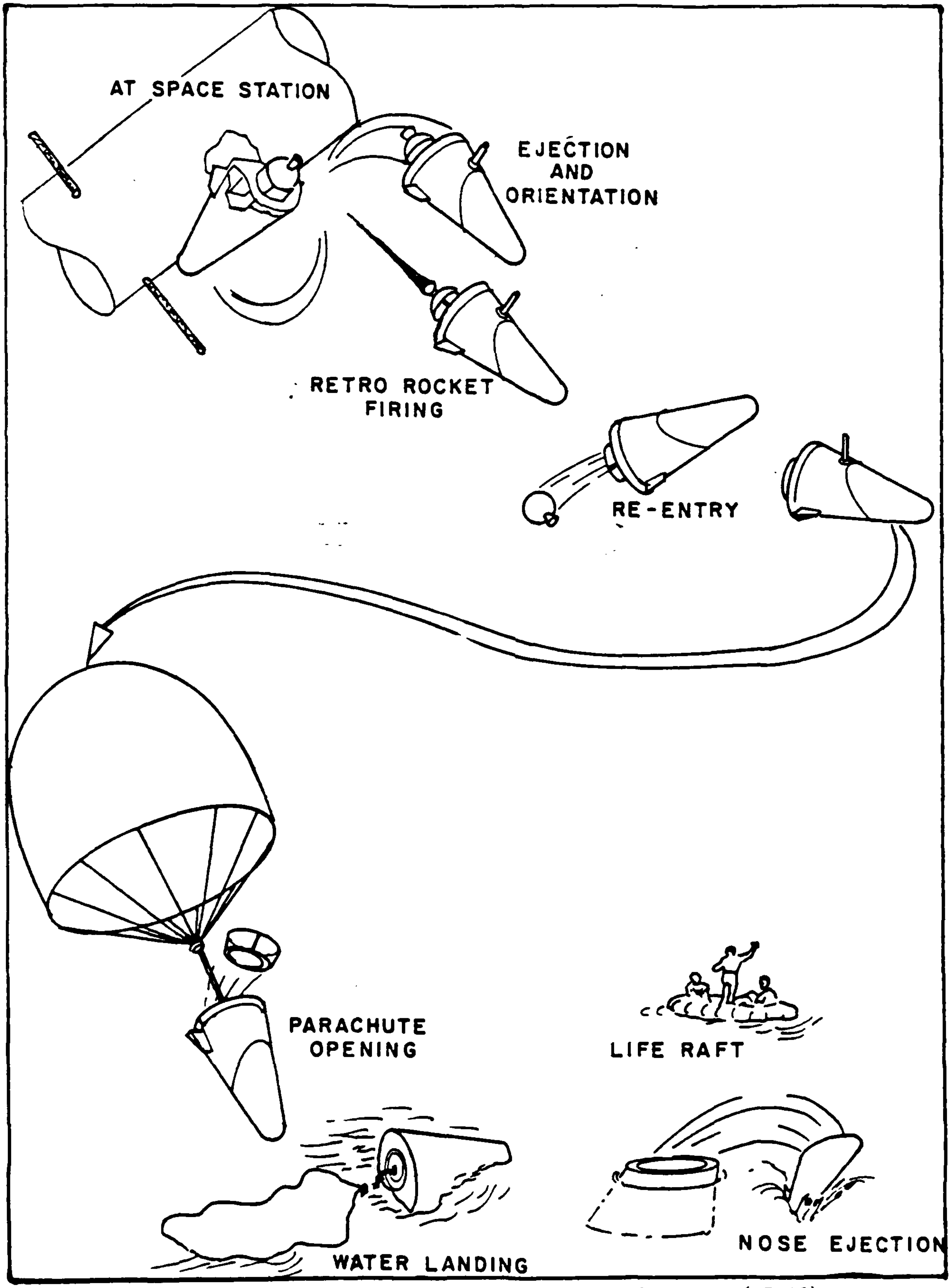


Fig 3.14 Satellite Life Boat Operating Sequence (37:49)

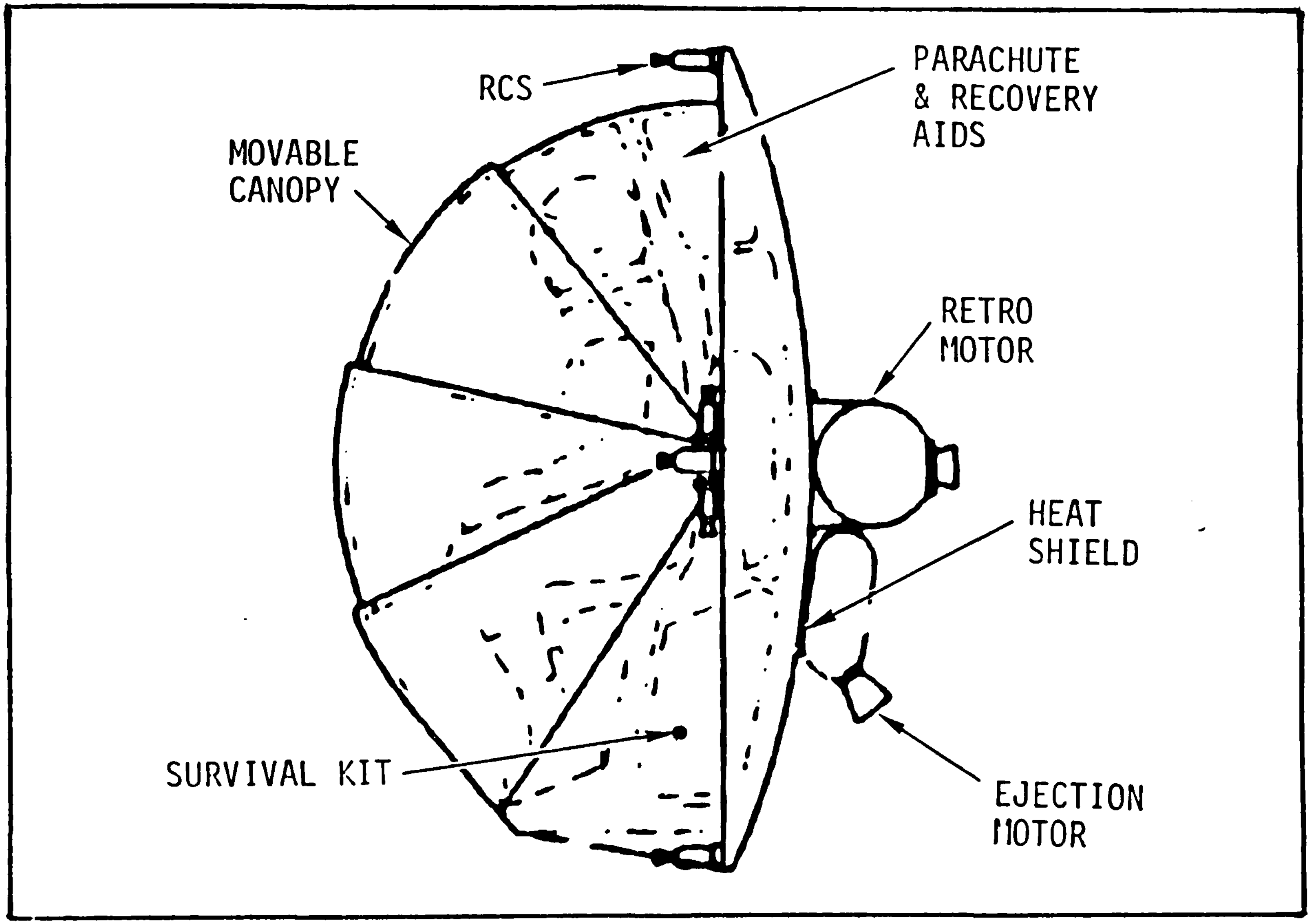


Fig 3.15 Egress Escape Device (36:70)

the Egress system jettison from the space station. The Egress escape capsule has a pressurization system allowing a shirt-sleeve environment. Either manual or automated controls position the Egress system for proper orientation for retro-rocket firing and re-entry. Contained on the escape capsule is a parachute recovery system, recovery and locating aids, and a survival kit. From figure 3.15 it appears that the escaping astronaut disengages the heat shield and canopy at some point after re-entry and descends to earth using the parachute attached to the ejection seat.

Airmat (see Fig. 3.16) (36:72). This escape device is basically the same as the Paracone emergency escape system. Airmat is a two-man inflatable system incorporated around a dual ejection seat. As on the previous device, information on the actual size and operation of Airmat is limited. The inflated Airmat completely encloses the two escaping crew members on all sides, after they have ejected from the space station. The inflated structure insulates the crew from the heat of re-entry. The type of attitude control and retro-fire controls is unknown, however, the size and shape of the Airmat system points to a parachute recovery instead of aerodynamic drag used in the Paracone escape device.

Rib-Stiffened Expandable Escape System (see Fig. 3.17) (36:58). This three-man escape system is stored in a canister and expands into an articulated rib-truss structure covered by a synthetic material. The escape system contains an environmental control unit that allows a shirt sleeve environment for the escaping crew members. The attachment point for the canister and the entry and activating principles for the Rib-Stiffened

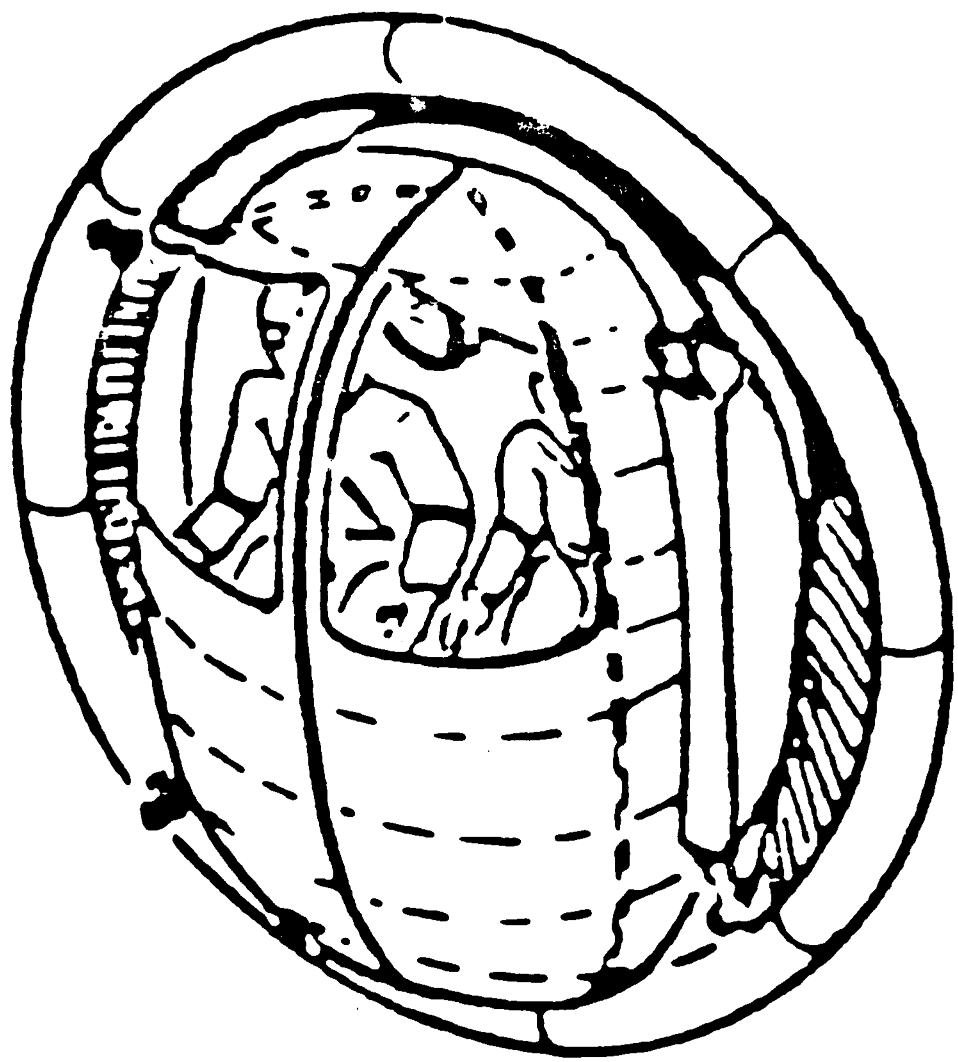


Fig 3.16 Airmat Escape Device (36:72)

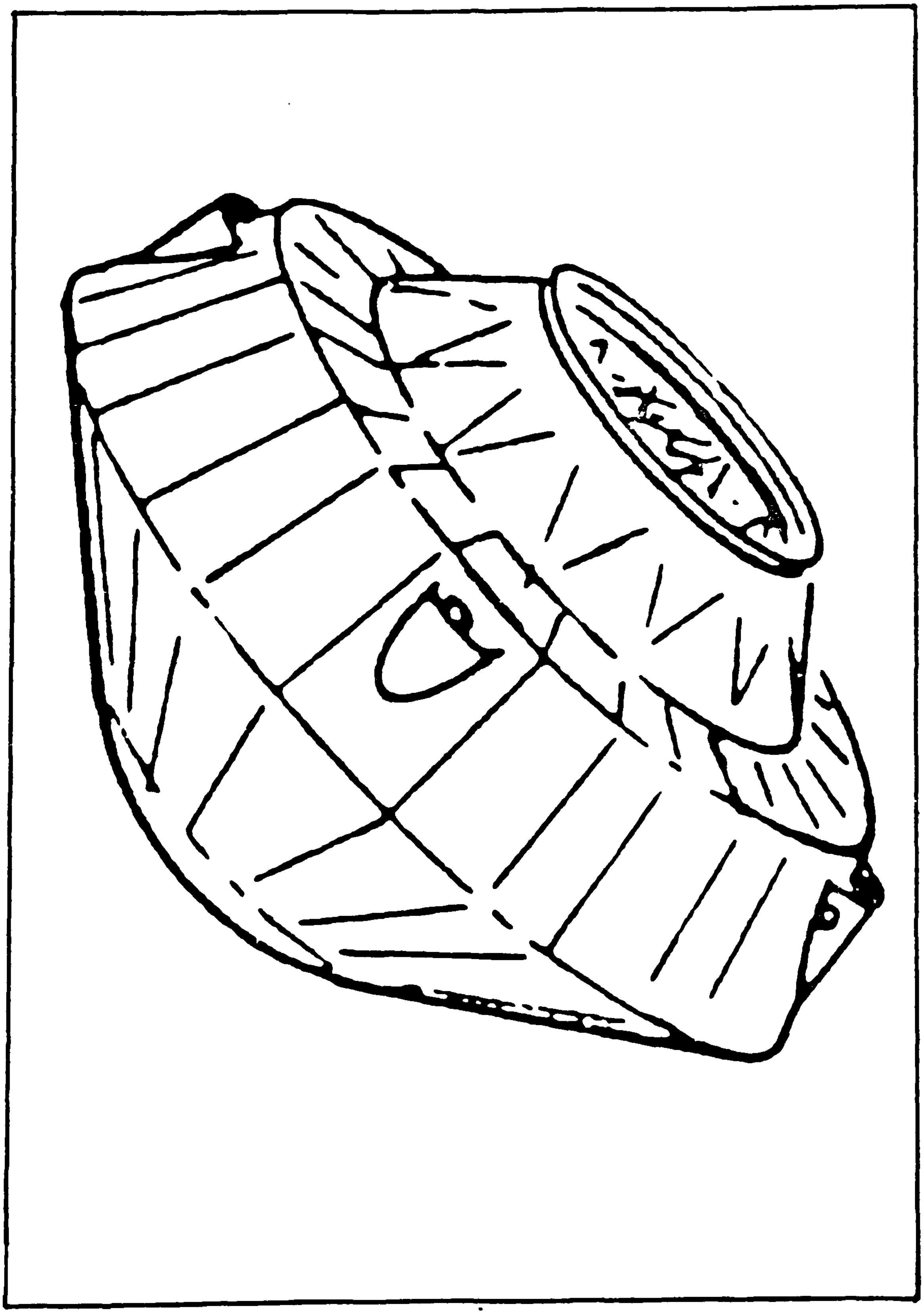


Fig 3.17 Rib-Stiffened Expandable Escape System (36:72)

Expandable Escape System must allow direct access from the interior of the space station to maintain the shirt sleeve principle. In order to accomodate this, the canister is probably attached to the side of the space station with an open hatch to the interior of the station. The operation of the device was not disclosed in the referenced document and, as of this writing, the Rockwell Corporation was reluctant to disclose proprietary information regarding the Rib-Stiffened Expandable Escape System and the Saver Escape System discussed next.

Saver (see Fig. 3.18) (36:73). The Saver escape system is a unique one-man emergency escape and recovery mechanism that employs a large, lightweight, inflatable balloon to modulate drag and deceleration loads during re-entry. The balloon also takes the place of a parachute recovery system when the astronaut is in the dense atmosphere of the earth. The escaping astronaut requires an EVA space suit and self-contained life support equipment to utilize this escape system. Specifics on Saver are unavailable, however, the supporting figure depicts a capsule which the escaping crew member enters and then jettisons from the space station. The balloon exhibits a large radar cross-section that would aid recovery efforts of ground personnel. Attitude control and retro-rocket firing mechanisms are not depicted in the supporting figure but would be necessary items for operation of the Saver system.

The last four alternatives mentioned, Egres, Airmat, Rib-Stiffened, and Saver escape systems, are not included in the detailed analysis later in this chapter. Each of these systems were possible alternatives that had

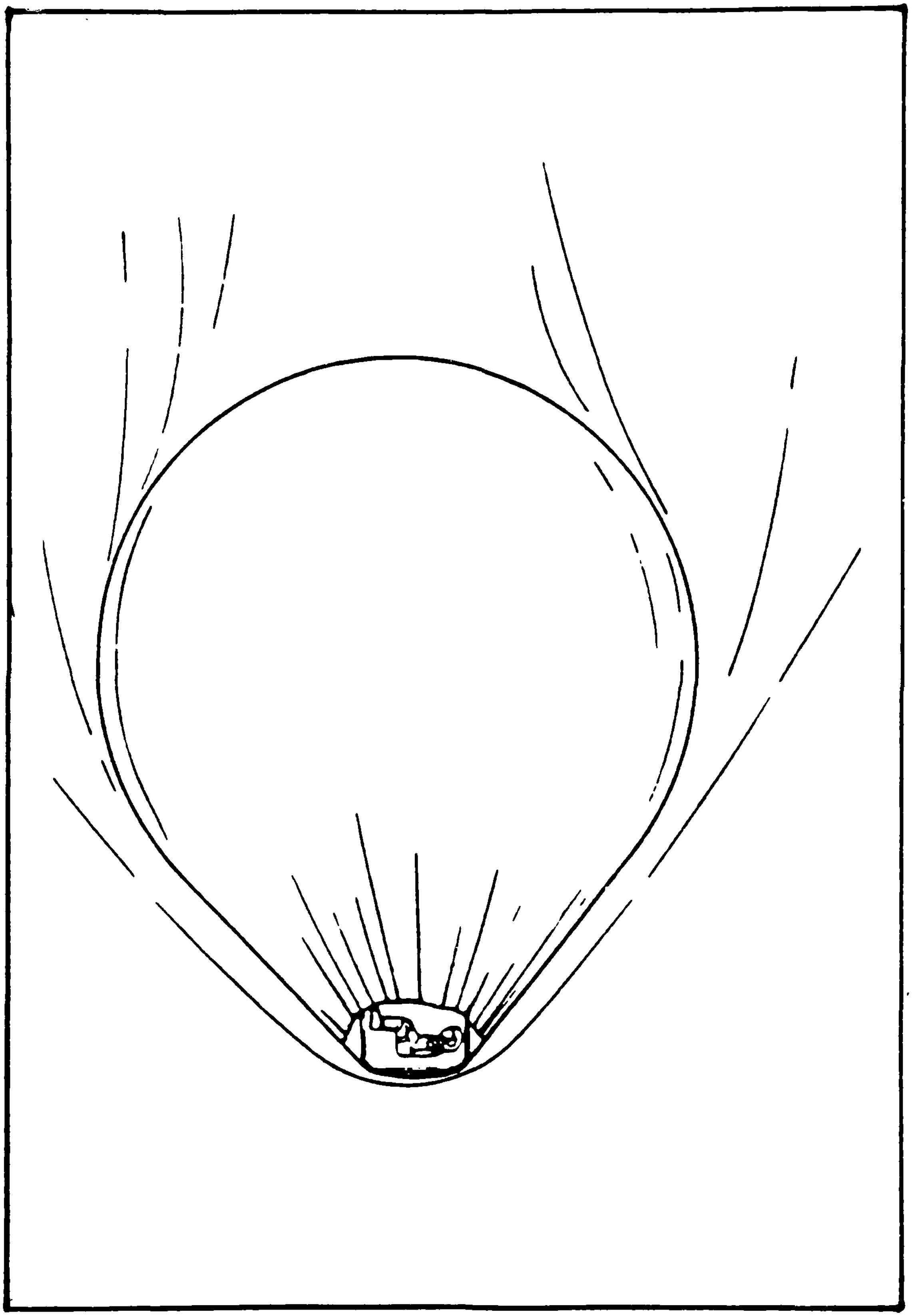


Fig 3.18 Saver Escape Device (36:73)

been mentioned in the literature. However, sufficient data was not available on these alternatives to warrant a reasonable analysis. It should be noted that they resemble previously discussed alternatives. The Egress system is similar to MOSES and the Satellite Life Raft in that it is a rigid capsule. Its unique quality a movable canopy that envelopes the escaping astronaut. Airmat is very similar in design to Paracone and the Expandable Disc Re-Entry Module. Airmat did not appear to have a unique advantage or difference from either of those designs. The Rib-Stiffened expandable escape concept is basically a soft-sided capsule with an environmental control system. Although eliminated from further analysis, its compact storage in a canister is a distinct advantage. The Saver escape system incorporates a balloon for modulating drag and deceleration during recovery. The relative merits of this over a standard parachute recovery system is unknown.

Apollo Command Module (see Fig 3.19, 3.20) (45:26) The final alternative is based on the cone-shaped re-entry vehicle used during the Apollo space program. The Apollo Command Module has on access hatch at the apex of the cone. The round base is covered by an ablative heat shield for protection of the crew during re-entry. The interior of the command module, originally designed for a crew of three, can accommodate a total of six with a basic interior redesign. The module contains pressurization and life support equipment capable of maintaining a shirt sleeve environment thus eliminating the need for space suits. As an escape device for the space station, the module would be attached to a connecting node with the

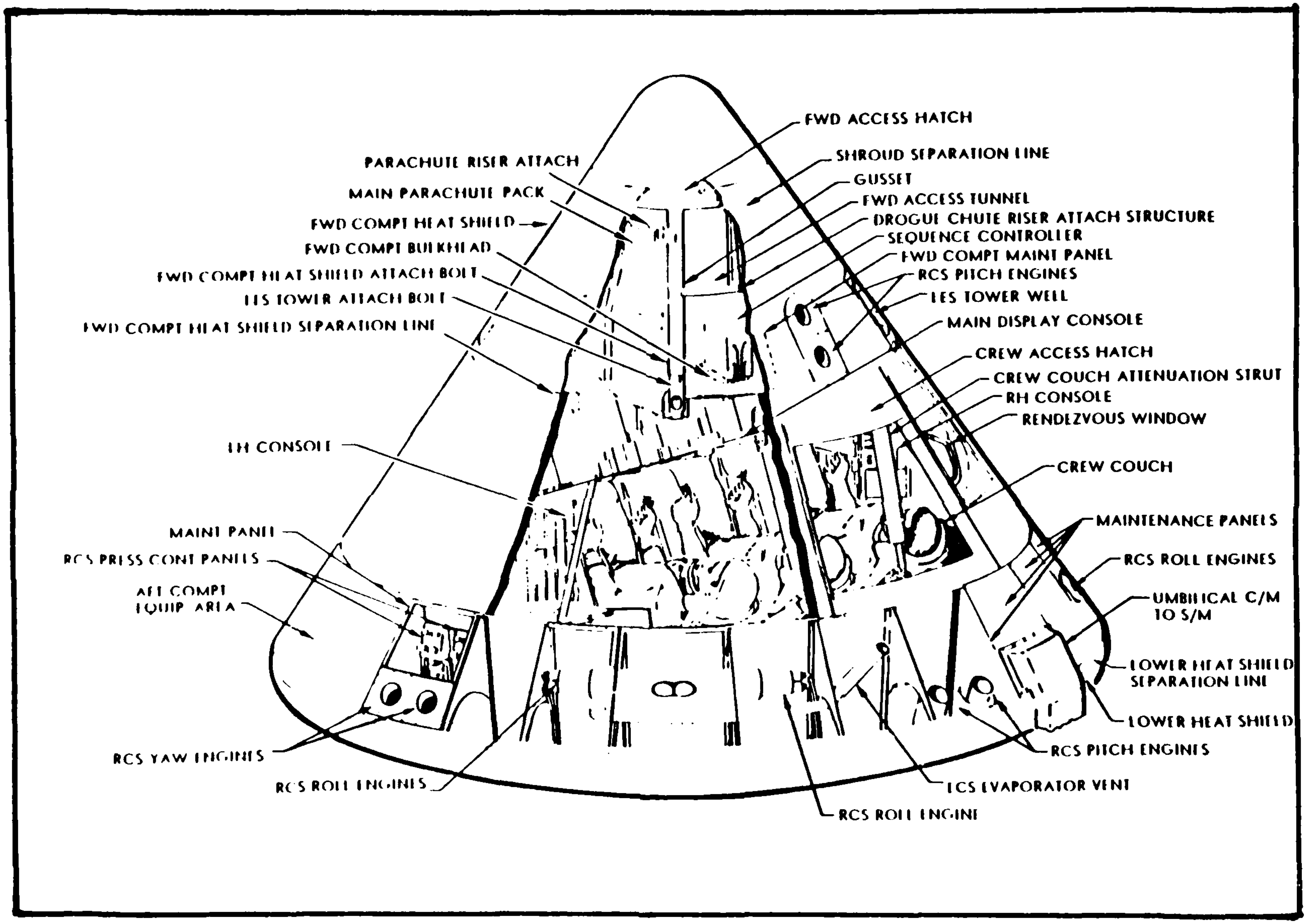


Fig 3.19 Apollo Command Module (26:377)

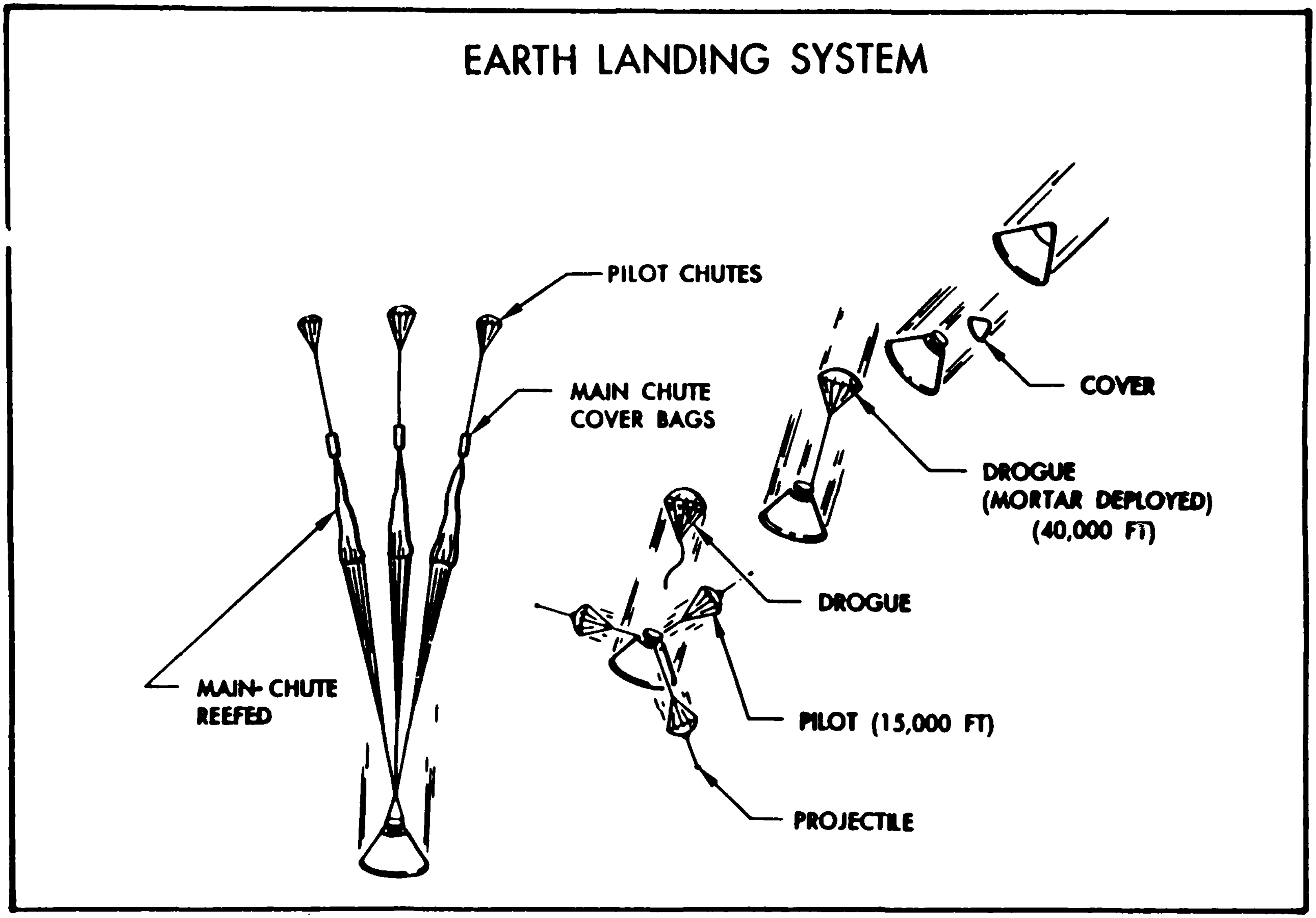


Fig 3.20 Command Module Landing Sequence (45:87)

access hatch open to the interior of the space station. This allows rapid entry into the escape module when the need arises.

In an escape scenario the crew would enter the module, secure the access hatch, secure themselves in the crew couches, and then separate from the space station by explosively terminating seals and clamps holding the module to the space station. One of the astronauts operating the Apollo Command Module controls would fly the module clear of the station and properly orient it for retro-rocket firing. Once in proper position the astronaut would activate a retro-rocket package, causing the module to de-orbit. The ablative material composing the heat shield protects the astronauts as they enter the earth's atmosphere back first. At an altitude of approximately seven kilometers two drogue parachutes are deployed from the tip of module (45:82). These drogue chutes slow and stabilize the module until, at approximately four kilometers, they separate from the module and three main parachutes are deployed for the final descent to a water landing. The Apollo Command Module is capable of floating but not designed for land impact. Although original Apollo Command Modules contained complex support, control, communication, and navigation equipment a module designed as an escape system would be of a more basic design. The system would include controls for stabilizing and retro-rocket systems along with basic communications, locating, and survival equipment.

ANALYSIS

The analysis of the fifteen alternative space escape systems is divided into two parts. The first is a preliminary analysis that reduces the number of alternatives considered for detailed analysis. The second

part is a detailed analysis of the remaining alternatives according to the objectives outlined in chapter II. The detailed analysis is accomplished for two different manning scenarios that are discussed in the detailed analysis.

Preliminary Analysis. Table 3.1 lists all of the alternatives to be evaluated in the preliminary analysis. This portion of the overall analysis eliminates nine of the original fifteen alternatives from further consideration. Each of the alternatives are discussed as to why or why not they should be considered in the detailed analysis.

The first of the alternatives is the Expandable Disc Re-entry Module. This alternative is eliminated from further consideration due to it's similarity to the Paracone. Further evaluation of the Expandable Disc would be redundant at this level of detail. The selection of the Paracone (instead of the Expandable Disc Re-Entry Module) for further investigation was arbitrary.

The next alternative is the Maneuverable Entry Research Vehicle (MERV). As discussed in the alternatives section this device incorporates a lifting body capable of atmospheric flight. For this investigation, a lifting body escape vehicle of some type requires detailed investigation, therefore MERV is included in the detailed analysis section. Although not exactly the same as MERV, the Satellite Lifeboat system uses a lifting body design similar to MERV. Due to the similarities of the two systems, and the fact that supporting information on MERV is more current, the Satellite Life Boat will not be included in the detailed analysis.

Table 3.1

Alternatives Considered In Preliminary Analysis

Expandable Disc Re-entry Module

Maneuverable Entry Research Vehicle (MERV)

Emergency Astronaut Re-entry Parachute System

Inflatable Orbital Escape Device

Manned Orbital Space Escape System (MOSES)

Paracone

Hermes Minishuttle

MOOSE

Satellite Life Raft

Satellite Life Boat

Egress

Airmat

Rib-Stiffened Expandable Escape System

Saver

Apollo Command Module

The Emergency Astronaut Re-Entry Parachute incorporates a unique approach to emergency escape from the space station. Due to this unique approach it is included in the detailed analysis. This escape system, consisting of a special parachute-spacesuit combination will naturally be met with some skepticism. The idea of de-orbiting and re-entering the earths atmosphere in a spacesuit attached to an expanded parachute could develop concern in the ranks of the astronaut corps.

The next escape device to be eliminated from further evaluation is the Inflatable Orbital Escape Device. This device is basically an inflated ball in which an escaping crew-member re-enters the atmosphere. The device is similar to MOOSE (Man Out Of Space Easiest) in that it is a flexible one man unit that is inflated prior to de-orbit. Due to these basic similarities MOOSE will be evaluated in the detailed analysis instead.

An evaluation of escape systems would not be complete without including a rigid, blunt-nosed pod. General Electric's Manned Orbital Space Escape System (MOSES) is included in the detailed analysis for that reason. The design is based on systems that have accomplished hundreds of flights and successful recoveries over the past twenty years (28:1). It does not use a lifting body, inflatable structure, or any unique technical design. MOSES is an example of a basic escape system different from the other systems previously outlined.

The next escape system is the Paracone inflatable escape device. As discussed earlier it is similar to the Expandable Disc and is included in the detailed analysis.

The Hermes minishuttle is a smaller vehicle similar to the U.S. Space Shuttle. Initially proposed as an alternative, it is not included in the

detailed analysis due to the tremendous cost involved. The development of an untested Hermes is expected to cost over six billion dollars (3).

The MOOSE system is an inflatable device that is included in the detailed analysis in lieu of the Inflatable Orbital Escape Device mentioned earlier. Even though MOOSE incorporates varying density foaming agents, instead of compressed gas to form the inflated structure, it is sufficiently similar to the Inflatable Orbital Escape Device to warrent it's evaluation alone. The operational procedures, capabilities, and design of the two systems are identical making a detailed analysis of both a duplication of effort. MOOSE was selected for further evaluation due to the availability of more support data.

Neither the Satellite Life Raft or Life Boat are considered for the detailed analysis. The Satellite Life Raft is basically a one man MOSES and, as discussed above, MERV will be evaluated instead of the Satellite Life Boat.

The Egress, Airmat, Rib-Stiffened Expandable, and Saver escape systems are not included in the detailed analysis. Adequate information was not available on these systems, however the relative merits of each were discussed in the alternatives section along with their similarities to other alternatives.

The final space escape alternative is the Apollo Command Module. It is included in the detailed analysis since it is the only alternative that has actually been used in manned missions. It's proven design merits it further consideration and evaluation. Table 3.2 lists all alternatives included in the detailed analysis.

TABLE 3.2
Alternatives Considered In Detailed Analysis

Maneuverable Entry Research Vehicle (MERV)

Emergency Astronaut Re-Entry Parachute System

Manned Orbital Space Escape System (MOSES)

Paracone

MOOSE

Apollo Command Module

Detailed Analysis. This part of the analysis analyzes the remaining six alternatives according to the measures of effectiveness in table 2.1. This is accomplished for two different manning scenarios. In the first, the total number of crew-members on the space station is three. In the second scenario the total number on board is increased to eight.

Prior to evaluation some general assumptions are made that cover both scenarios. The first assumption is that all personnel on board the space station require emergency escape. Therefore, the number of escape devices required of each alternative depends on the capacity of the particular system and the scenario under which the evaluation is taking place. Another assumption is that all escaping astronauts are healthy and uninjured. All astronauts are assumed to be inside the space station living module. For an accurate comparison it does not matter which module the crew is in , so long as it is assumed that their location and activity is identical for each alternative in the two scenarios evaluated. It is also assumed that two EVA space suits are on the space station. Additional space suits necessary for an escape alternative are considered a cost for that particular device. For example, if the analysis is for the three man scenario and three space suits are required for the alternative being examined then the additional cost of one suit is added to the overall cost of the escape device.

3-Man Scenario. In this scenario three crew-members require emergency escape from the space station. The analysis for this scenario begins with a description of the six alternatives in terms of the number of each required and their respective location on the space station. The

detailed analysis is then accomplished by determining the value of the measures of effectiveness in the order presented in table 2.1 for each of the six alternatives.

The first alternative is MERV. This lifting body vehicle was presented earlier as having a capacity of three. In this scenario, therefore, only one MERV is required. It is located in a docked position attached to a node connected to the habitation module similar to the shuttle docked in figure 2.4. Since MERV has it's own life support system no space suits are required.

The second alternative is the Emergency Astronaut Re-Entry Parachute syatem. This device is an ejection seat located along the walls of the living module. From the inside of the module the device appears to be a contoured seat. From the outside of the module there is no protrusion since the device is flush with the exterior skin. As discussed earlier, the device ejects from the space station with an astronaut strapped in the seat. The escaping astronaut requires a special space suit and parachute to de-orbit in. This type of suit is different from a typical EVA suit in that it requires higher heat resistance for the astronaut to survive re-entry. Each space suit, therefore, is included as a cost item. Three complete systems consisting of an ejection seat, parachute, and special space suit are required. All units are attached to the living module in such a way that they clear the truss support structure when ejected.

The third alternative is MOSES. For this scenario a four man capacity unit is attached to the outermost connecting node that is connected to the living module. The rounded end of the MOSES unit is pointed away from the geometric plane that includes the dual keel trusswork and is in the same

geometric plane with all of the main modules. MOSES requires all escaping astronauts to be in space suits, therefore, one additional space suit is included in the system. This type of MOSES uses the rectangular gliding parachute with an automatic homing device instead of the standard round recovery parachute.

The fourth alternative is the Paracone inflatable space escape system. This system is based on a single person ejection seat. For this scenario, three Paracones are required. They are located in the same place as the ejection seats for the Emergency Astronaut Re-entry Parachute System, all in the living module of the space station. Since a total of three EVA space suits are required, one suit is included in the cost of this alternative for the three-man scenario.

The fifth alternative is MOOSE. This escape device is a one-person inflatable escape system that uses plastic foam as the inflating agent. For escape, an astronaut requires a pressurized EVA space suit. The astronaut would egress the space station via an air lock with the deflated MOOSE around him. For this scenario, three EVA suits and three MOOSE systems are required. The MOOSE are stored in the living module. Again, the additional EVA suit is included in the cost of this alternative.

The final alternative is the six-man capacity Apollo Command Module (CM). This rigid escape device is located at the exterior connecting node of the living module with the heat shield facing away from the module. Since it has a capacity of six only one CM is required. No space suits are required due to the environmental control system of the CM.

The next step is to compute the value of the measures of effectiveness for each of the six alternatives. The measures of effectiveness and how they are calculated are given in the same order as presented in Table 2.1.

A. Low Technological Risk

The measure of effectiveness (MOE) for this objective was discussed in Chapter II. The degree of technical feasibility is measured using a three-level scale with the highest being current technology required, medium being advanced technology required, and the lowest level where a major technological breakthrough is required.

The Maneuverable Entry Research Vehicle is rated as a medium. The basic concept of a high lift to drag ratio re-entry vehicle is a possibility given our current work on the space shuttle. Since a vehicle such as this is in the developmental stages and a workable design is not complete, the technical requirements can be considered advanced (16;17).,

The Emergency Astronaut Re-entry Parachute System is rated low. According to a NASA space-suit expert, a space suit capable of re-entering the earth's atmosphere has not been designed (32). Such a space suit and parachaute system are also questionable in terms of reliability.

The Manned Orbital Space Escape System is rated as a medium. The basic design of the re-entry capsule has been used for years (28). Reconfiguration of the design to accommodate personnel will require a certain degree of advanced technology. It is not rated highest since it has not been used by live test subjects.

Paracone is rated low. A flexible fabric capable of withstanding re-entry would be a major achievement. The reliability of such an untested escape device is also considered low.

The MOOSE system is also rated low. The technical development and testing of an inflatable device that uses various density foams as a barrier between an escaping crew member and the heat generated during re-entry is considered a major accomplishment.

The Apollo Command Module is rated high. This escape device is the only man-tested device that uses current or old technology.

B. Simplicity

The MOE for simplicity is a three-level scale of high, medium, and low. A high level of simplicity corresponds to little or no tasks required of the escaping crew in using the escape system. For this level of simplicity, an escape system is basically autonomous or can be controlled by personnel other than the escaping crew. The medium level of simplicity corresponds to the crew being required to accomplish simple tasks. The low level of simplicity means a pilot astronaut is needed to operate the escape device.

The Maneuverable Entry Research Vehicle is rated low since it requires a pilot-astronaut for its operation (16;17).

The Emergency Astronaut Re-entry Parachute System is rated high. The escaping crew member is only required to eject from the space station in an ejection seat device. He does not fire any retro rockets but simply de-orbits due to a combination of gravity and parachute drag (15).

The Manned Orbital Space Escape System is rated high due to its full autonomy (31:5).

The Paracone escape device is rated medium. The escaping astronaut is required to activate attitude control, jets and a simple solid propellant retro-rocket (23:111).

The MOOSE system is rated medium. An escaping crew member is required to use a hand-held retro-rocket (37).

The Apollo Command Module is rated medium. One of the escaping astronauts is required to control attitude and retro-rocket firing.

C. Minimum Weight

For this objective, the mass of the escape device is the MOE. The unit of measure is kilograms for the total structure where the total structure is the sum of the various system masses found in the noted support documents. A conversion factor of 2.2 lbs=1 kilogram was used when necessary. Mass is rounded to nearest kilogram.

MERV (16:20)

Fuselage Skin & Structure	1190 Kg
Landing Gear Nose	114
Main	340
Fins and Actuators	91
Body Flap	182
Plumbing	114
RCS	80
Propellants	114
Electrical	273

Avionics		182
ECS/Environmental Control System		408
Controls		91
Residuals		91
Cooling		128
Mechanisms		45
	TOTAL	3443 Kg

Several items should be noted in the system masses above. The total mass does not include air breathing engines for atmospheric flight since they were eliminated to accommodate a crew of three. Also the environmental control system weight was tripled to accound for three escaping personnel instead of one.

Emergency Astronaut Re-entry Parachute (33:10)

Space Suit and Parachute		180 Kg
Ejection Seat		172
Ejection Propellant		12
		364 Kg
(Three units required)	TOTAL	1092 Kg

The supporting information on the above system contained a total weight only. The break down of the weight into the systems noted above are estimates.

MOSES (29:159)

1 Additional Space Suit	80 Kg
Structure	250
Thermal Protection System	204
Attitude Control System	33
Propusion	150
Electrical	78
Recovery	78
Landing Attenuation	26
Separation	22
Ballast	58
Gliding Parachaute Homing and Controls	25
TOTAL	1004 Kg

The weight for the gliding parachute homing equipment and manual override controls were estimated. Note that the additional space suit required beyond the assumed number of suits available is included in the mass of the MOSES.

Paracone (23:112)

1 Additional Space Suit	80 Kg
Ejection Seat	172
Propellants and Retro-rocket	20
Inflatable Structure	20
	292 Kg

(Three units required with only

one additional space suit.) TOTAL 716 Kg

The supporting document gave the value of the total mass of being between 137 and 230 Kg for a complete Paracone. The mass for the ejection seat was increased to be comparable to the mass of the ejection seat used for the Emergency Astronaut Re-entry Parachute system. The break down of the weight into the systems noted above are estimates. Note that three units are required for this scenario but only one additional space suit is included in the mass.

MOOSE (37)

1 Additional Space Suit	80 Kg
Survival Kit	5
Beacon	3
Recovery Aids	5
Parachute	7
Foamed Vehicle	90
Foam Tanks	9
Propulsion	85
	284 Kg

(Three units required with only

one additional space suit.) TOTAL 692 Kg

Apollo Command Module (44:A-3)

Pressurized Structure		668 Kg
Mechanisms		99
ACS		94
RCS (Reaction Controls)		340
Fuel Cells		31
Power Distribution		1378
ECLS (Environmental Controls)		251
Crew Accommodations		146
Command and Control		276
	TOTAL	3283 Kg

Note that some devices on the original CM are not included. An example is the lunar module adapter used for docking purposes in the original Apollo program.

D. Minimum Cost

The MOE for this objective is the total cost of the alternative in 1986 dollars. The total cost is defined as the cost in dollars for design and development, test and evaluation, and flight hardware for a complete system. Costs were calculated using the space station cost model from NASA's Johnson Space Center in Houston, Texas (44:21). This model incorporates cost estimating relationships based on subsystem weights and historical data. The model and actual calculations are not included in this paper due to proprietary concerns of the NASA contractor who developed

the model (4). The cost for additional non-specialized EVA space suits is based on a marginal unit cost of $4 million (32). All costs are given in $ millions.

MERV

Design and Development		$231.1
Test and Evaluation		315.3
Flight Hardware		65.1
	TOTAL COST	$611.5

Emergency Astronaut Re-entry Parachaute

Design and Development		$ 38.2
Test and Evaluation		91.4
Flight Hardware		55.8
	TOTAL COST	$185.4

MOSES

Design and Development		$150.0
Test and Evaluation		180.7
Flight Hardware		31.6
	TOTAL COST	$362.3

PARACONE

Design and Development	$ 15.3
Test and Evaluation	76.0
Flight Hardware	46.6
TOTAL COST	$139.7

MOOSE

Design and Development	$ 22.0
Test and Evaluation	90.0
Flight Hardware	47.5
TOTAL COST	$159.5

Apollo Command Module

Deign and Development	$181.6
Test and Evaluation	159.6
Flight Hardware	168.9
TOTAL COST	$510.1

It should be noted that the design and development and the test and evaluation costs for the Apollo command module are one tenth of the amount calculated in the cost model. This was done so that sunk costs, those costs already incurred in past efforts, were not included. Costs for redesign as an escape system were included. Actual costs may differ from all of the above estimates due to the limitations of the model used and the lack of precise subsystem weights for the various alternatives.

Cost estimation is a difficult and often inaccurate task. In this evaluation, the same model was used in an effort to compare the relative costs of the different alternatives with a higher degree of accuracy. The face value of these estimates are considered good enough for the scope of this thesis and should not be considered as in-depth estimates for use in a technical investigation of any one of the alternatives alone.

E. Minimal Volume

The MOE for this objective is the volume displaced by the stored escape mechamisms mesured in cubic meters. The calculations were accomplished using standard geometrical relationships. In most cases, the volume was obtained by generalizing the shape of the escape system to a simpler form and then calculating the volume.

The Maneuverable Entry Research Vehicle was generalized to be a triangular pie-shaped wedge with a triangle base of 4 meters, a length of 7.6 meters, and a depth of 1 meter. Figure 3.2 shows that this approximation is reasonable and sufficiently accounts for the volume displaced by the vertical rudder and other flight surfaces. The total volume is 15.2. cubic meters.

The Emergency Astronaut Re-entry Parachute has a volume of 6 cubic meters. No data exists on the actual size of this system. Based on SR-71 ejection seats used in early space shuttle flights an estimate of 2 cubic meters per unit was used (37). The total volume is for three units required in this scenario.

The Manned Orbital Space Escape System (31:4) has a calculated volume of 11.5 cubic meters. MOSES' shape was generalized as a cylinder with a

diameter of 2.54 meters and a length of 2.276 meters. The actual volume is somewhat less than calculated; however, for the purpose of this analysis, the calculated value is sufficiently accurate for comparison with other alternatives.

The Paracone's volume is 6 cubic meters for all systems needed in this scenario. The actual size of this system is unknown; however, it uses an ejection seat similar to the Emergency Astronaut Re-entry Parachute. The displaced volume was estimated to be the same for both systems.

The MOOSE systems have a volume of 1.5 cubic meters. The volume for ech stored unit is estimated at 0.5 cubic meters. Recall for this scenario three units are required to accommodate all escaping personnel.

The Apollo Command Module (5:41) calculated volume is 12.7 cubic meters. The CM is basically a cone with a diameter at its base of 3.9 meters and a height of 3.2 meters.

F. Quick to Enter and Escape

The MOE for this objective is time measured from the moment it is decided to egress the space station to when the escape device is physically clear of the space station. All personnel are required to egress the space station.

A certain amount of time is required for any particular activity in space. Some typical times for various activities in space were found. It takes each individual approximately 30 minutes to don a complete EVA space suit (32). For EVA work, or for using an escape system in zero pressure, an astronaut must pre-breath pure oxygen for 3.5 hours to aviod the bends (8). In addition, it would take another 10 minutes to use an air lock to

exit the space station (2). To access an escape system is assumed similar to an Air Force pilot entering and strapping himself into the cockpit of an F-4 aircraft. A pilot's estimation of the time required to accomplish such a task is 30 seconds (48). If in a complete space suit, the time is doubled to allow for the difficulty in movement.

When using MERV as an escape system, the three escaping astronauts must travel to the connecting node where it is docked. The time to travel this distance is a matter of seconds in the weightlessness of space (32). Since all three must enter through one hatch, the total time allowed is 1 minute and 30 seconds, 30 seconds for each crew member. The last crew member secures the hatch and they prepare to disengage from the space station. Approximately 5 minutes are allowed to separate from the space station. The total time to enter and escape is therefore 6 minutes and 30 seconds.

The Emergency Astronaut Re-entry Parachute System requires more time since each astronaut must don a space suit and pre-breath. These tasks are assumed to be accomplished at the same time for a total time to enter and escape of 4 hours.

MOSES requires all crew members to be in space suits also. Again, all three enter the escape device through a single hatch. The suits are donned simultaneously taking approximately 30 minutes. Entry into MOSES, with space suits on, takes a total of three minutes. Approximately 5 minutes are required to separate from the space station. The total time to enter and escape is 38 minutes.

The Paracone escape system requires the same time as the Emergency Astronaut Re-entry Parachute System. The total time is 4 hours to enter and escape.

MOOSE is the only device that requires all three escaping crew members to use an air-lock. All most don a space suit, pre-breath, then exit the space station through the air-lock. Assuming all of these are accomplished simultaneously, the total elapsed time to escape is 4 hours and 10 minutes to escape.

The Apollo command module requires all astronauts to enter through a single hatch, secure themselves, prepare the module for separation, and then to initiate separation. This time required is the same as that for MERV. The total time is therefore 6 minute and 30 seconds.

G. Minimize G Forces

The MOE for this objective is the maximum re-entry deceleration through the vertical axis of the vehicle in Gs. A G is the acceleration of a body due to gravity at sea level, which is 9.78 meters per second squared. No clearly defined method of calculating exact deceleration on any given object was developed in this research. The values listed below, found in the noted support documents, are the maximum Gs encountered in re-entry from the approximate altitude of an orbiting space station.

Alternative	Maximum Gs
MERV (17)	1.5
Emergency Astronaut Re-entry Parachute(33:12)	8.0
MOSES (28:48)	6.6
Paracone (23:111)	11.0
MOOSE (7)	8.0
Apollo Command Module (5:53)	4.0

H. Alternative Uses

This objective attempts to maximize the use of an escape system by analyzing its potential in areas other than emergency escape. Rather than compare the relative significance of different uses for an escape device, the MOE is simply the number of practical alternative uses the device could accomplish without major redesign.

For this evaluation, three basic alternative uses are considered:

(1) Use as a place for crew members to be alone

(2) A device to de-orbit inanimate objects requiring no crew,

(3) A manned vehicle capable of maneuvering about in free space and then redocking with the space station.

These three summarize other uses for the alternative space escape systems. Of course, all systems are designed to be capable of bringing an astronaut back to the surface of the earth; therefore, other purposes of de-orbiting personnel are not considered. It should be noted that identifying specific reasons for the above alternative uses, such as testing or gathering data, is not a concern. In the following analysis of

the alternative escape systems, (1), (2), and (3) correspond to the first, second, and third alternative uses listed above.

MERV can accomplish (1) and (3), but cannot de-orbit successfully without a crew. Under this criteria, a MERV has two alternative uses, therefore it is rated as a 2.

The Emergency Astronaut Re-entry Parachute system is capable of being used as an escape system only. It is given a rating of 0 alternative uses.

MOSES can accomplish (1) and (2). It is not capable of (3) since redocking capabilities would require redesign. The rating is 2 for this system.

The Paracone system is based on an ejection seat that, when activated, has adverse effects on the interior of the space station. It is considered limited to escape only and is rated 0 for this MOE.

The MOOSE system is also limited to escape use due to its dependence on a space-suited astronaut. The rating for it is 0.

Without major redesign, the Apollo Command Module is capable of (1) and (3). It is not a fully autonomous system that can de-orbit on its own. It is rated a 2 according to the criteria for this evaluation.

I. Controllability

The objective here is the ability of the escape vehicle to be manually controlled by the escaping crew in the atmosphere of the earth. The measure of effectiveness is a three-level scale for the degree of controllability. The highest level on the scale corresponds to a vehicle that the escaping crew can fly in the atmosphere in such a way as to be able to make course corrections typical of a vehicle with a high lift to

drag ratio. The medium level corresponds to an escape device that has manual controls allowing the escaping crew to make minor atmospheric course corrections to avoid earthbound structures, trees, canyons, water vessels, and other things that should make a landing dangerous. The lowest level corresponds to an escape device that basically descends where the wind blows it. Such vehicles often incorporate round parachutes in the final stage of re-entry.

MERV is rated as high. It is the only alternative with a high lift to drag ratio that glides in the atmsphere in the same way that the space shuttle does.

The Emergency Astronaut Re-entry Parachute is rated low in this objective. The escaping astronaut has little maneuverability in the final descent to the surface of the earth.

MOSES is rated as a medium for this scenario it was assumed MOSES is constructed with the rectangular gliding parachute system with manual override controls (31:6).

The Paracone escape system is rated low. For this emergency escape alternative the crew-member has no ability to control the device in the atmosphere.

MOOSE is also rated low. Its final descent is slowed with the aid of a single circular recovery parachute. This parachute is not controlled by the crew member in any way that could allow it to avoid obstacles.

The Apollo Command Module is rated low. The basic design calls for three large parachutes to be deployed to slow the capsule to a safe landing speed. These chutes are not manually controlled.

J. Land or Water Recoverable

The MOE for this objective is yes/no. If the system can be recovered on land or water, the MOE is yes. If the escape system is limited to water recovery, or limited to land recovery, but not capable of both, then the MOE is no. The results are listed in Table 3.3, along with the summary for all of the previous measures of effectiveness.

8-Man Scenario. For this situation, eight crewmembers require emergency escape from the space station. Since none of the altrnatives have a capacity of 8, the number required of each system will increase for this scenario. This changes the value for three measures of effectiveness for the objectives of minimum weight, minimum cost, and minimum volume. The remaining objectives and their corresponding measures of effectiveness calculated in the three-man scenario do not change. In this portion of the analysis, the number of each system required and their respective locations are determined. This is followed by a summary of the changes for the three objectives mentioned above for each alternative escape device.

The first alternative, MERV, has a capacity of three. To accommodate all eight crewmen, three MERVs are required. Each is docked at a connection node. One at the same location in the 3 man scenario and the remaining two at the two middle connecting nodes (see Figure [illegible]).

For the one man Emergency Astronaut Re-entry Parachute escape alternative, a total of eight are required. Four would [illegible] living module and four in the laboratory module.

The next alternative is the four man [illegible] docked at the same location as in the pre[illegible]

AD-A179 233 A SYSTEMS ANALYSIS OF EMERGENCY ESCAPE AND RECOVERY 2/2
SYSTEMS FOR THE US SP. (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. B K KELLY
UNCLASSIFIED DEC 86 AFIT/GSO/AA/86D-5 F/G 6/7 NL

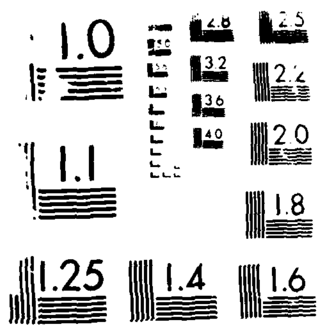

1.0
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

Table 3.3
Results of Detailed Analysis for 3 Man Scenario

	MERV	Emergency Astronaut Re-Entry Parachute	MOSES	Paracone	MOOSE	Apollo Command Module
No. of Systems Required	1	3	1	3	3	1
Low Technological Risk	Medium	Low	Medium	Low	Low	High
High Simplicity	Low	High	High	Medium	Medium	Medium
Low Weight(Kilograms)	3443	1092	1004	716	692	3283
Low Cost($Millions)	611.5	185.4	362.3	139.7	159.5	510.1
Low Volume (Cubic Meters)	15.2	6	11.5	6	1.5	12.7
Quick to Use (Hrs:Mins:Secnds)	0:6:30	4:0:0	0:38:0	4:0:0	4:10:0	0:6:30
Minimal G Force (Acceleration in G's)	1.5	8	6.6	11	8	4
Alternative Use	2	0	2	0	0	2
Controlability	High	Low	Medium	Low	Low	Low
Land or Water Recoverable	No	No	Yes	Yes	Yes	No

for a total of two, is docked to the node connecting the living and Japanese experiment modules (see Figure 2.6).

Eight Paracone escape systems are required for this scenario. They are located the same as the Emergency Astronaut Re-entry Parachute system.

The next alternative is MOOSE. These single person escape systems are stored in the living module. A total of eight are required.

The final alternative, the Apollo Command Module, has a capacity of six. Two systems are required and they are docked the same as the MOSES escape system is assumed to be docked.

The calculation of the MOEs for the objectives of minimum weight, minimum cost, and minimum volume were accomplished the same as before. In this scenario, the weight increases as the number of devices required increases. The cost increases as the number of devices, or flight hardware, increases. Additional cost for space suits beyond the initial assumed quantity is also added in the total cost. The volume increases directly as the number of devices required increases. The results are tabulated in Table 3.4 along with the unchanged vaules for the other objectives.

Summary. The values of the measures of effectiveness have been determined for all six alternative systems in two separate manning scenarios. The next step in the analysis is to compare the alternatives in terms of their measures of effectiveness. This is accomplished in the next chapter along with a discussion of further concerns and areas of future evaluation.

Table 3.4
Results of Detailed Analysis for 8 Man Scenario

	MERV	Emergency Astronaut Re-Entry Parachute	MOSES	Paracone	MOOSE	Apollo Command Module
No. of Systems Required	3	8	2	8	8	2
Low Technological Risk	Medium	Low	Medium	Low	Low	High
High Simplicity	Low	High	High	Medium	Medium	Medium
Low Weight(Kilograms)	10,329	2,912	2408	2176	2112	6566
Low Cost($Millions)	741.7	298.4	409.9	230.7	252.0	679.0
Low Volume (Cubic Meters)	45.6	16	23	16	4	25.4
Quick to Use (Hrs:Mins:Secnds)	0:6:30	4:0:0	0:38:0	4:0:0	4:10:0	0:6:30
Minimal G Force (Acceleration in G's)	1.5	8	6.6	11	8	4
Alternative Use	2	0	2	0	0	2
Controlability	High	Low	Medium	Low	Low	Low
Land or Water Recoverable	No	No	Yes	Yes	Yes	No

IV. Conclusions

The final chapter of this investigation begins with a discussion of Multi-attribute Utility Theory (MAUT). A version of MAUT is used to determine the overall utility of each of the six alternatives. The next section shows the findings of the applied theory for this analysis. Recommendations are then made on the "best" escape system and areas requiring further evaluation. The study concludes with an overall summary of the report.

Multi-attribute Utility Theory

The version of Multi-attribute Utility Theory used in this investigation is based on the class notes from Operations Research 6.33 at the School of Engineering, Air Force Institute of Technology. The decision maker (DM) responsible for this analysis is assumed to be an EMV'er who's overall utility is additive. Another assumption is that the decision maker's utility functions for the various attributes or objectives are linear (12). The interested reader may find further explanation of MAUT in OPER 6.33 class notes or other Management Science texts such as Decisions with Multiple Objectives: Preferences and Value Tradeoffs by Keeney and Raiffa and Multiple Criteria Decision Making by Zeleny.

The DM used in this thesis was Mr. Lanny Jines of the crew Escape and Subsystems Branch of AFWAL at Wright-Patterson Air Force Base, Ohio. Mr. Jines is a registered Professional Engineer with over 13 years experience in crew escape systems used in military aircraft. He is also a certified instructor pilot with over 1400 flight hours. He currently is

investigating space escape for future military space systems. His opinion is considered to match general opinion in the field regarding priority of objectives. Mr. Jines assigned a weight to each of the ten objectives used in the analysis. The sum of the weights equals 100. These weights, along with the individual utility functions for each objective, are used in the calculation of the overall utility for each slternative. Table 4.1 shows the assigned weights used in both the 3 and 8-man scenarios.

Determining the utility functions for each of the ten objectives is straightforward. For each objective the best value of the MOE is given a utility of 1, the worst value a utility of 0. With the value of the MOE being the X axis and the utility being the Y axis, the straight line that connects the points for best and worst MOE yields the utility function for that objective. Three of the objectives have an MOE based on a three level subjective scale (see table 3.3). For these the utility is 1, 0.5, and 0 for the best, middle, and worst value of the MOE. One objective, land or water recoverable, has either a utility of 1 for yes or 0 for no.

Calculation of the overall utility for each of the alternatives is also straightforward. First, the individual utility for each alternative and every objective is calculated. The overall utility for an alternative is found by summing the product of objective weight and individual utility for all the objectives. The highest possible utility for any alternative is 100. Table 4.1 lists the results for the 3-man scenario and table 4.2 for the 8-man scenario.

Table 4.1
Individual and Overall Utilities
3-Man Scenario

Objective	Weight	MERV	Emergency Astronaut Re-Entry Parachute	MOSES	Paracone	MOOSE	Apollo Command Module
High Reliability	20	.50	0	.50	0	0	1
High Simplicity	15	0	1	1	.50	.50	.50
Low Weight	10	0	.86	.89	.99	1	.08
Low Cost	10	0	.90	.53	1	.96	.21
Low Volume	5	0	.67	.27	.67	1	.18
Quick to Use	15	1	.04	.87	.04	0	1
Minimal G Force	5	1	.32	.46	0	.32	.74
Alternative Use	10	1	0	1	0	0	1
Controlability	5	1	0	.5	0	0	0
Land or Water Recoverable	5	0	0	1	1	1	0
Overall Utility		45.00	38.15	73.40	36.35	38.70	60.00

Table 4.2
Individual and Overall Utilities
8-Man Scenario

Objective	Weight	MERV	Emergency Astronaut Re-Entry Parachute	MOSES	Paracone	MOOSE	Apollo Command Module
High Reliability	20	.50	0	.50	0	0	1
High Simplicity	15	0	1	1	.50	.50	.50
Low Weight	10	0	.90	.96	.99	1	.46
Low Cost	10	0	.87	.65	1	.96	.12
Low Volume	5	0	.71	.54	.71	1	.48
Quick to Use	15	1	.04	.87	.04	0	1
Minimal G Force	5	1	.32	.46	0	.32	.74
Alternative Use	10	1	0	1	0	0	1
Controlability	5	1	0	.5	0	0	0
Land or Water Recoverable	5	0	0	1	1	1	0
Overall Utility		45.00	38.45	76.65	36.55	38.70	64.40

Findings

In both scenarios MOSES had the highest overall utility with 73.40 and 76.65 for the 3 and 8-man scenarios respectively. The next highest overall utility was the Apollo Command Module with 60.00 and 64.40. The remaining four alternative had overall utilities ranging from 36.55 to 45.00 in both scenarios. A difference of 10.00 in overall utility is considered significant for the DM weighting criteria.

To check the sensitivity of the overall utilities to the weights, table 4.3 contrasts the results from above versus the results when all objectives are equally weighted. To do this each objective is assigned a weight of 10 so that the highest possible overall utility remains 100. The overall utility for MOSES remains the highest for both scenarios at 70.20 and 74.80. The Apollo Command Module drops in overall utility to 47.10 and 53.00 for the 3-man and the 8-man scenarios but remains second best. The remaining alternatives' overall utility range from 37.90 to 47.80 for the equal weighting. This weighting tends to separate MOSES from the other alternatives more so than shown in the DM weighting.

While not included in tabulated results the effect of adding an environmental control and life support system (ECLS) to MOSES was considered. Assuming the ECLS adds $200 million (44) and 100 kilograms to the MOSES alternative for the 3-man scenario, the time to use the system drops from 38 minutes to 6.5 minutes. Using MAUT as described above, the overall utility for the 3-man scenario using DM meights is 70.75 and for equal weights it is 66.90. The reduction of the overall utility values compared to those calculated earlier shows the relatively small difference

Table 4.3
Comparison of Overall Utilities for DM Weighting And Equal Weighting

Scenario	Weighting Method	MERV	Emergency Astronaut Re-Entry Parachute	MOSES	Paracone	MOOSE	Apollo Command Module
3-Man	DM	45.00	38.15	73.40	36.35	38.70	60.00
	EQUAL	45.00	37.90	70.20	42.00	44.60	47.10
8-Man	DM	45.00	38.45	76.65	36.55	38.70	64.40
	EQUAL	45.00	38.40	74.80	42.40	47.80	53.00

in utility is not significant enough to show a return on a $200 million investment, especially since it decreased.

Performance levels were also analyzed to see what is required to change the preference order. If the Apollo Command Module was fully automated, modified to include a controllable recovery parachute, and included impact alternative equipment making it capable of land recovery, (all for under $62 million) its overall utility would increase to 76.2 and 80.7 for the 3-man and 8-man scenario using the DM weighting. This would give it an overall utility slightly higher than that for MOSES. The relative difference between the overall utilities for MOSES and the CM would not be significant.

Recommendations

The purpose of using a systems analysis approach to problem solving is to find an alternative that can best solve the problem at hand. The MOSES alternative consistently showed the highest overall utility in both scenarios and for both weighting criteria. The next best alternative was the Apollo Command Module, although not as consistent in maintaining its overall utility in the different situations. The MOSES escape device appears to be the best system for emergency escape from the space station according to the criteria and scope outlined in this thesis.

Several areas not covered in this research merit further investigation. One centers around the difficulty of emergency escape for injured astronauts. What concerns and limitations are there for injured personnel other than minimizing G forces? An injured astronaut may not be capable of wearing a space suit. Another area of concern not addressed in

this thesis are astronauts involved in EVA at the time of an emergency. Can an escape device handle crew men in such a situation, or is it a realistic concern? Another possible investigation centers on using an escape device as an orbital transfer vehicle (OTV). The OTV may become an integral part of the space station. Doubling it's use as an escape system may be less expensive and more effective than having two independent devices.

A more detailed analysis comparing the Apollo Command Module and MOSES across a wider spectrum of manning scenarios could reveal additional useful information. If the crew size is increased to 12 then only 2 Apollo Command Modules, the same required for the 8-man scenario, are needed while the MOSES alternative would require a total of 3 units. Further investigation into the feasibility and cost savings of using existing Apollo Command Modules is warranted. The location of either escape system for best escape routes and safety during ejection can also be analyzed. A destroyed or altered escape route changes the complexity, posing the problem of having an escape device that cannot be used.

Summary

Given the recent Space Shuttle Challenger accident the level of interest in space safety has risen to new heights (34). The focus of this thesis, emergency escape from the space station, is a critical safety issue. In this analysis objectives to be met by an effective escape device were identified along with their corresponding measures of effectiveness. Alternative escape systems were found that could be used on the manned core portion of the space station complex. Fifteen systems were initially

identified. A preliminary analysis reduced these alternatives to the following six which permitted further detailed analysis: the Maneuverable Entry Research Vehicle, Emergency Astronaut re-entry Parachute system, Manned Orbital Space Escape System, Paracone, Man Out of Space Easiest (MOOSE), And the Apollo Command Module. The detailed analysis consisted of subjective evaluations and calculations of the measures of effectiveness for each of the previously identified objectives. This was accomplished for all of the final six alternatives in two different manning scenarios, a 3-man and an 8-man scenario. Finally, using multi-attribute utility theory and weighting criteria from the thesis sponsor, MOSES was found to consistantly rate the highest overall utility. The next best alternative according to it's calculated overall utility was the Apollo Command Module. The final recommendation is to compare MOSES and the Apollo Command Module in a more detailed analysis. The issues to be further investigated include evaluating larger manning requirements, evaluating potential docking locations for multiple escape routes, and examining the use of an escape device as an orbital transfer vehicle (OTV).

Bibliography

1. AFWAL/FIER Crew Escape and Subsystems Branch Preliminary Contractor Proposal, June 1986.

2. Airlock 2201 Orbiter/Airlock/Hatch Systems. NASA Report, LBJ Space Center, Houston TX.

3. Ashley, Howard. Hermes Cost Estimate. LBJ SPace Center, Houston TX, December 1985.

4. Ashley, Howard. Personal Interview. LBJ Space Center, Houston TX, September 24, 1986.

5. Booker, P. J. et al. Project Apollo The Way to the Moon. American Elsevier Publishing Co., New York, 1969.

6. Campbell, J. A. and J. V. Capuzzo. Investigation of Location and Retrieval Criteria for Re-entry Crew Escape Systems. Technical Report. IIT Research Institute, Chicago, March 1964.

7. Chapman, D. R. An Approximate Analytical Method for Studying Entry Into Planetary Atmospheres. NASA Paper TR R-11. 1959.

8. Clarke, Margaret M. and Mark A. Bronez. "Telerobotics for the Space Station." Mechanical Engineering. February 1986.

9. Dalton, Maynard. NASA Drawings. LBJ Space Center, Houston TX, July 22, 1986.

10. Davis, Dr Jeff MD. Phone Interview. LBJ Space Center, Houston TX, July 23, 1986.

11. "ESA Tentatively Accepts U.S. Space Station Participation Bid." Aerospace Daily, 52-53. April 9, 1986.

12. Feldman, Maj Ken (USAF). Lecture: Notes in Oper 6.33. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, January 1986.

13. "France Proposes Minishuttle Spacecraft." Aviation Week and Space Technology, 17:(August 8, 1983).

14. Griswald, H. R. and R. B. Trusch. "Emergency and Rescue Considerations for Manned Space Missions." Acta Astronautics, 8, 1123-1133, 1981.

15. Heath, Gloria W. "1974 Annual Survey of Recovery Capabilities." Science and Technology Series, 37:205257, 1974.

16. High Leverage Hypervelocity Technology Development. Task 1 Review, Boeing Aerospace Company. March, 1986.

17. High Leverage Hypervelocity Technology Development. Air Force Contract F33615-85-C-3015, Task 1 Review. Rockwell International, March 1986.

18. Hodge, John D. NASA Distribution Letter. NASA Headquarters, Washington DC, May 5, 1986.

19. Jines, Lanny A. Trip Report, Johnson Space Center. AFWAL/FIER, May 2, 1986.

20. Jines, Lanny A. Trip Report, Johnson Space Center. AFWAL/FIER, July 9, 1985.

21. Johnson, C. C. U.S. Patent 3,330,510. Filed January 19, 1967, granted July 11, 1967.

22. Johnson, Malcom. Contractor Drawings. LBJ Space Center, Houston TX, July 22, 1986.

23. Kendall, R. T. "Space Rescue on Inflatable, Open Re-entry Cone." Space/Aeronautics, 39:110-117, 1963.

24. Kessler, Donald J. "Summary of Orbital Debris Workshop." Science and Technology Series, 58:3-10, 1982.

25. Louviere, A. C. Phone Interview. LBJ Space Center, Houston TX, July 21, 1986.

26. Manned Spacecraft: Engineering Design and Operation. Fairchild Publications, Inc., New York, 1964.

27. Mavriplis, F. "Re-Entry Crew Escape Module Concepts for Orbital Vehicles." Aerospace Proceedings 1966, 1:535-559, 1966.

28. Mayer, Roland T. "Manned Orbital Escape." AIAA Papers, 79-0870: 46-56, May 1979.

29. Mayer, Roland T. "MOSES (Manned Orbital Space Escape System) - A Hypothetical Application." Journal of Spacecraft and Rockets, 20:158-163, 1983.

30. Mayer, Roland T. Space Station Egress and Return System. General Electric Re-Entry Systems Operations Briefing Paper: Philadelphia, PA, February 1983.

31. Mayer, Roland T. "MOSES - A Hypothetical Application." AIAA Papers, 81-0438:1-11, February 1981.

32. McBarron, James. Personal Interview. LBJ Space Center, Houston TX, September 25, 1986.

33. Murray, James J. and Fred R. DeJarnette. "An Emergency Astronaut Re-Entry Parachute System." Science and Technology Series, 37:7-16, 1974.

34. NASA Memorandum for the Record. Washington DC, April 11, 1986.

35. NASA Space Station Office. Space Station Design and Technology Utilization. Briefing Paper. NASA Langley, NASA, March 1986.

36. Peercy, B. and L. A. Rockoff. Space Station Crew Safety Alternatives Study. Third Quarter NASA Report. Ames Research Center, Moffett Field, March 1985.

37. Peters, James M. Escape Systems for Space Vehicles. White Paper. Wright-Patterson AFB, AFWAL/FIER, August 1983.

38. Reagan, Ronald, President of the United States. State of the Union Message. Washington DC, January 25, 1984.

39. Rockoff, Lisa. Phone Interview. Lockheed Corporation, July 30, 1986.

40. Sage, Andrew P. Methodology for Large Scale Systems. New York. McGraw-Hill, 1977.

41. "Shaping the Space Station: A Conversation with John Hodge." Space World, 13-17 May 1986.

42. Sibila, Alfred I. "Emergency Supply and Return Capability of a Space Station Support Vehicle." Science and Technology Series, 41:171-182, 1975.

43. Smith, Dallas G. Debris Impact on Earth-Orbiting Spacecraft. NASA Contractor Report. Marshall Space Flight Center, Alabama, 1984.

44. Space Station Cost Model. NASA Cost Model. LBJ Space Center, Houston TX, August 1985.

45. Sparks, Major James C., USAF (Ret). Moon Landing, Project Apollo. Dodd, Mead & Co., New York, 1969.

46. Storm, Richard. Review of Space Station Safety. NASA Briefing Paper. July 10, 1986.

47. Weinburg, Gerald M. Rethinking Systems Analysis and Design. Boston: Little, Brown and Company, 1982.

48. Williams, Stu Captain (USAF). Interview with an Air Force Pilot at Wright-Patterson AFB, OH, October 9, 1986.

49. Witcofski, Robert D. Space Station Crew Safety Requirements. Conference Paper. NASA Langley Research Center, June 7, 1983.

50. Wolf, Henry D. and Ross Fleisig. "Survey of Space Flight Safety Systems." Science and Technology Series, 41:1-32, June 1975.

51. Wolfe, M. G. et al. "Man-Made Space Debris - Implications for the Future." Science and Technology Series, 58:43-61, 1982.

VITA

Captain Brian Kelly was born on 21 November 1959 in Wheeler, Oregon. He graduated from Neah-Kah-Nie High School in Rockaway, Oregon in 1978 and attended The University of Portland on an ROTC scholarship. He qraduated Magnu Cum Laude with the degree of Bachelor of Science in Industrial Engineering and was commissioned in the USAF in May 1982. In June 1982 he served as Prime BEEF Officer, Deputy Chief of Operations, and Chief Environmental and Contract Planning in the 1001st Civil Engineering Squadron, Peterson AFB, Colorado, until entering the School of Engineering Air Force Institute of Technology, in May 1985.

Permanent Address: 339 North Easy Street

Rockaway, Oregon 97136

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release;
distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFIT/GSO/AA/86-D

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
School of Engineering

6b. OFFICE SYMBOL *(If applicable)*
AFIT/EN

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
Air Force Institute of Technology
Wright-Patterson AFB, Ohio 45433

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
See Box 19

12. PERSONAL AUTHOR(S)
Brian K Kelly, B.S., Captain, USAF

13a. TYPE OF REPORT

13b. TIME COVERED FROM ________ TO ________

14. DATE OF REPORT *(Year, Month, Day)*
December 1986

15. PAGE COUNT
111

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
22	02	
06	07	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Space Stations, Spacecraft, Space Capsules, Escape Systems, Escape Capsules

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Title: A SYSTEMS ANALYSIS OF EMERGENCY ESCAPE AND RECOVERY SYSTEMS FOR THE U.S. SPACE STATION

Thesis Chairman: Stuart Kramer, Captain, USAF
Assistant Professor

Approved for public release: IAW AFR 190-1.
Lynn E. Wolaver 12 Mar 87
LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Stuart Kramer, Captain, USAF

22b. TELEPHONE *(Include Area Code)*
513-255-6998

22c. OFFICE SYMBOL
AFIT/AA

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

AFIT/GSO/AA/86D-5

Abstract

Recent designs for the U.S. manned space station have crews on board the space station without any means of emergency escape for periods of up to 90 days. This investigation analyzes emergency escape and recovery systems for use on the space station in an effort to find the "best" escape device.

Initially, the objectives to be met by an effective escape device were identified along with with the corresponding measures of effectiveness (MOE) for each objective. Fifteen alternative escape systems were found that could be used on the manned core portion of the space station complex. A preliminary analysis reduced the number of alternatives considered for more detailed analysis to six. These final six, The Maneuverable Entry Research Vehicle (MERV), Emergency Astronaut Re-entry Parachute System, Manned Orbital Escape System (MOSES), MOOSE (Man out of Space Easiest), and Apollo Command Module, were compared on the basis of their calculated MOEs using multi-attribute utility theory.

The overall utilities for each of the final six alternatives were calculated for two crew sizes, 3-man and 8-man. MOSES was found to consistently rate the highest overall utility for both manning scenarios. The next best alternative was the Apollo Command Module.

Recommendations include examining the potential of using an escape device as an orbital transfer vehicle, and to conduct a future detailed comparison of MOSES and the Apollo Command Module for use on the space station as an emergency escape system.

END
5-87
DTIC